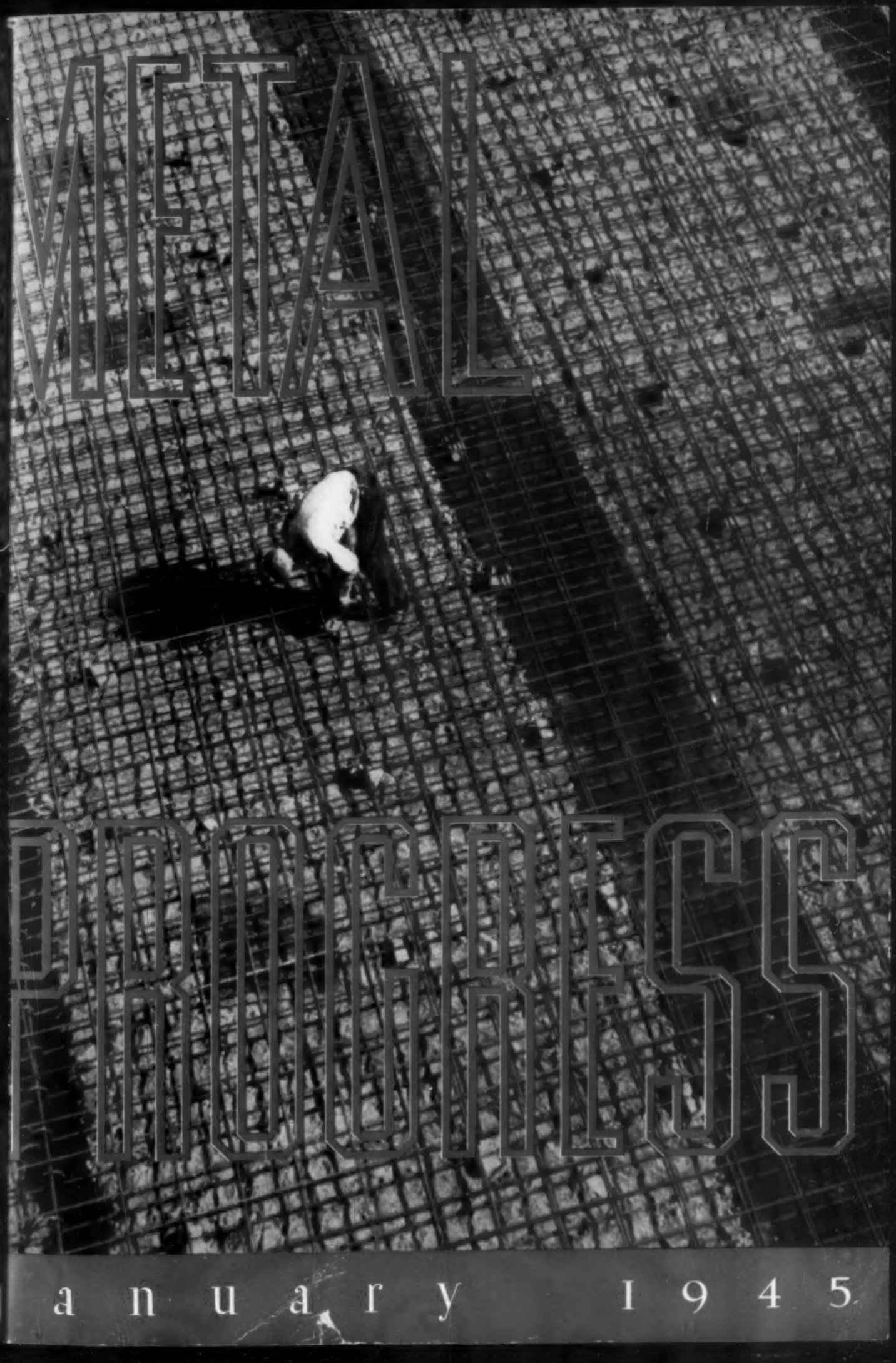
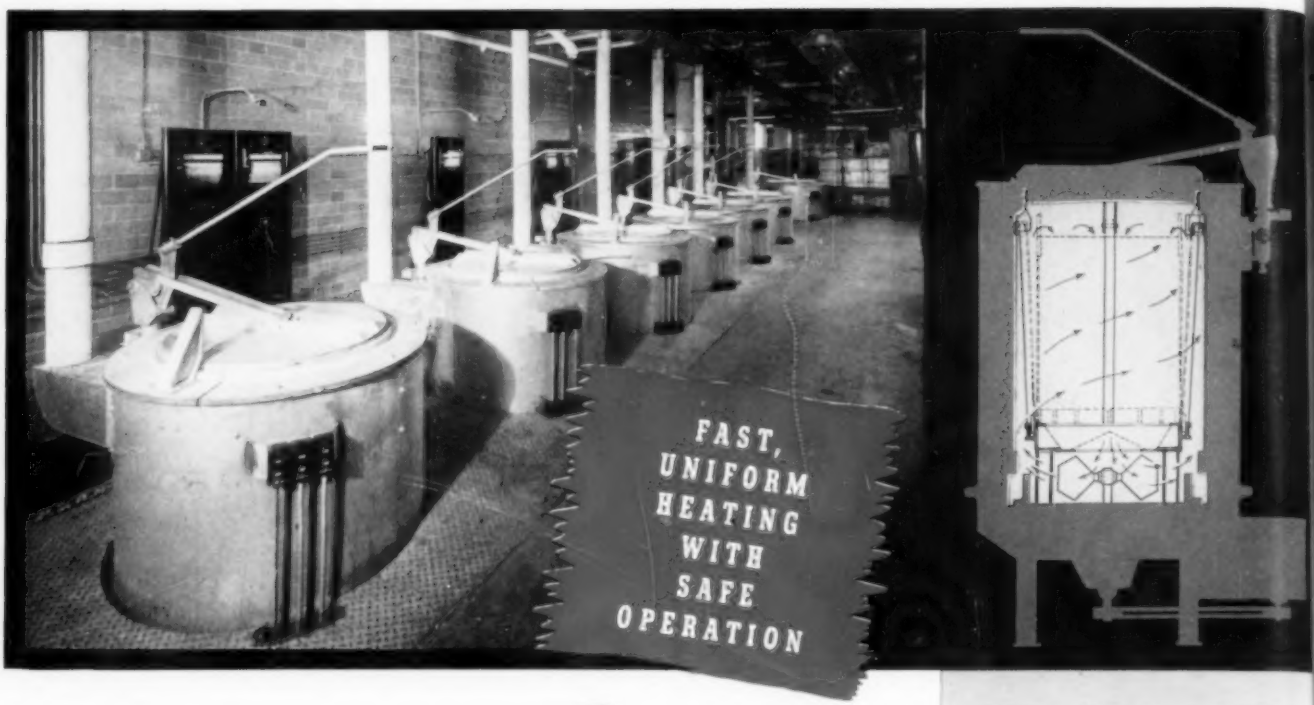
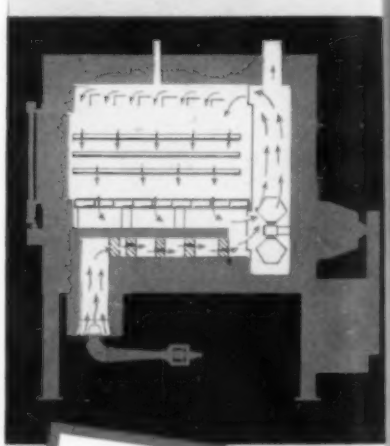

METAL
PROGRESS
January 1945



SURFACE COMBUSTION *Standard Rated* CONVECTION FURNACES

Cross sections shown above (Pit Type) and below (Oven Type) incorporate arrows to indicate the thorough circulation of hot gases within the furnace.



● Convection heating has become the most successful method of heating large masses of small parts quickly and uniformly. Furnaces to utilize this principle to the fullest extent must be equipped with a recirculating fan of large capacity and gas burner equipment for instantaneous operation. This, of necessity, involves additional operations to start and stop the equipment. The fan, the burners and the pilot must each be started in the proper sequence.

Surface Combustion Standard Rated Convection Furnaces are designed so that they can be easily equipped with Safeguard Control Units. These units are Factory Mutual Approved and automatically control the sequences of starting and the proper operation of the furnace. The operator need push only the start and stop buttons.

Standard Safeguard Control Units can be supplied with the furnace as accessory equipment and can be applied to the furnace at any time. Eliminate the human element, use the furnace that can be automatically safeguarded.

For complete data request Bulletin CG-43 **"DESIGN FEATURES OF SURFACE COMBUSTION STANDARD RATED CONVECTION FURNACES"**

The Heat Treater's Helping Hand **'Surface'**

SURFACE COMBUSTION · TOLEDO 1, OHIO

Standard and Special Industrial Furnace Equipment For:
Forging, Normalizing, Annealing, Hardening, Drawing, Carburizing, Nitriding and Heating. Special Atmosphere Generators. *Write for Bulletins.*

METAL PROGRESS

Vol. 47 **January, 1945** **No. 1**

Table of contents

Cover is a photograph fancifully named "Pattern in Steel" by the photographer, Jackson Edwards, of Los Angeles

Steel Cartridges of 3-In. Caliber 67
by Fred M. Arnold

Stress-Corrosion Cracking of Metals 75
Report of a recent symposium

Quality Steels -- Today and Tomorrow

Present Steelmaking Processes 79
by Earle C. Smith

Future Changes Reasonably to Be Expected .. 82
by H. B. Emerick

Reactions Between Hot Steel and Furnace Atmosphere 84
by Floyd E. Harris

Progress in the Mechanisms of Production .. 90
by Lester V. Colwell

Bits and Pieces

Who Knows About Temper Colors on Stainless Steels? 94
by Metallurgicus

"Blue Printing" on Metal 94
by H. J. Christy

Memory Aid for Welders 95
by E. James Sax

Hardness Tester With Automatic Certification Stamp 95
by Adolph Vlcek, Jr.

Drilling Pyrometer Holes Through Furnace Linings 95
by K. J. Trigger

Comprehensive Exposure Chart for Micrography 96
by Anton L. Schaeffler

Data Sheet: Exposure Chart for Bausch & Lomb Research Metallograph 96-B
by Anton L. Schaeffler

Properties and Characteristics of Magnesium Forgings 97
by J. Colin Smith

1944 War-Time Metal Finishes 102
by Harry P. Coats

Critical Points, by the Editor 105
Research in the U. S. Navy
New Laboratory for Magnetic Study
Perfect Ammunition
Research for Small Industry
Where are our Metallurgists Coming From?
Behold the Lowly Brake Shoe
Advanced Study of Castings
Something Wrong Here
Making Nickel and Its Alloys
Bright Annealing

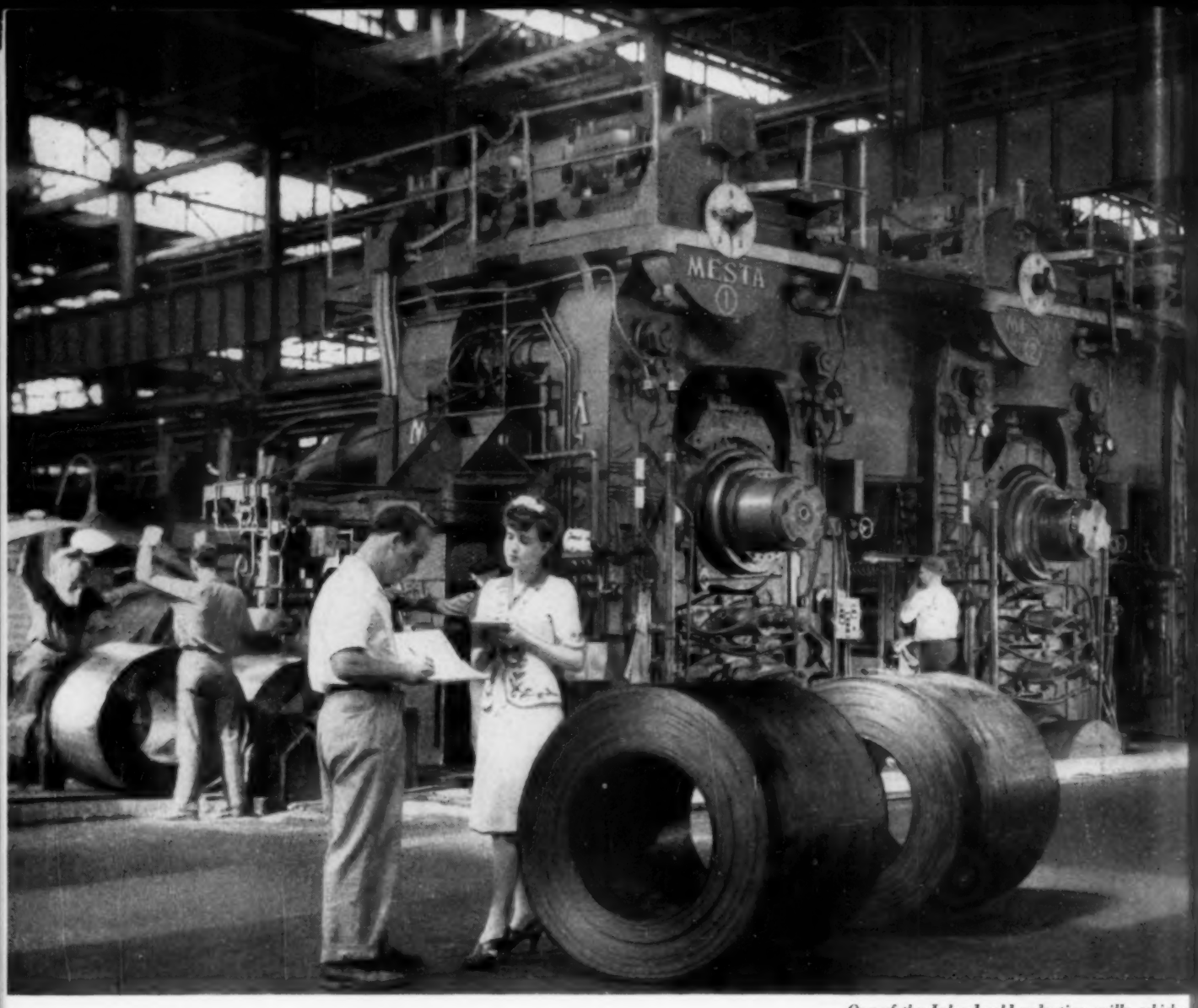
Personal Items 110, 112

Science of Spot Welding 114
by Wendell F. Hess
Extracts from a paper entitled "Recent Progress in the Scientific Application of Welding to Steel" read before the American Iron & Steel Institute, May 25, 1944

Literature From Advertisers, Free to Readers .. 118

Advertising Index 190

Copyright, 1945, by AMERICAN SOCIETY for METALS, 7301 Euclid Ave., Cleveland, Ohio. Published monthly; subscription $5 a year in U. S. and Canada. Current copies $1; special reference issues $2. Entered as second-class matter, Feb. 7, 1921, at the post office at Cleveland, under the Act of March 3, 1879.....The American Society for Metals is not responsible for statements or opinions printed in this publication. The Editor is sponsor for unsigned and staff articles....Requests for change in address should include *old* address of the subscriber.



One of the Inland cold reduction mills, which r
strip to precise thickness and produces a lustrous

For Finer Steel Products . . . Tomorrow

Consult Inland when plans are started for parts or products which must have the strength, utility, and beauty that can come only from steel sheets and strip.

Inland was among the first to install modern continuous mills. Its engineers and metallurgists have contributed many notable advancements to sheet and strip production methods and quality control —resulting in unsurpassed uniformity, workability, and finish.

Inland experts are ready to help you select the right steel for finer products and economical fabrication—whether the products are for wartime use, or for the markets that will follow Victory.

Sheets • Strip • Tin Plate • Bars • Plates • Floor Plate • Structurals • Piling • Rail • Track Accessories • Reinforcing Bars

INLAND STEEL COMPANY

38 S. Dearborn St., Chicago 3, Ill.

Sales Offices: **Cincinnati • Detroit • Kansas City • Milwaukee • New York • St. Louis • St. Paul**

METAL PROGRESS
Published by The American Society for Metals
Volume 47; January to June, 1945

STEEL CARTRIDGES OF 3-IN. CALIBER

By Fred M. Arnold
Metallurgist
Norris Stamping & Mfg. Co.
Los Angeles, Calif.

IN JULY 1941, a foreseeable shortage of brass prompted W. S. Knudsen — then head of the Office of Production Management — to request several companies to develop a steel cartridge case. One of these was the Norris Stamping and Mfg. Co. of Los Angeles, at that time an established manufacturer of large caliber brass cartridge cases. The project was thought to be well within the range of practicality, but no information was available about the real requirements of artillery cases. Despite this — or perhaps because of this lack of traditional practice, within four months steel cases had been made by at least eight different methods. Eventually four satisfactory manufacturing processes were in operation with minor variations in about 50 plants throughout the country. Enormous numbers of steel cartridges were made, especially in small calibers for side arms, thus saving thousands of tons of copper for more essential uses. However this is running ahead of our story.

On receipt of Mr. Knudsen's request, K. T. Norris, president of our company, proposed a method of quickly producing a few samples of cold drawn cases by modifying existing tools for the 75-mm. brass case. Nine sample cold drawn cases, having what was then thought to be the necessary yield strength in the steel skirt, were made within 12 days. They were successfully proof-fired in November 1941, and it is our understanding that these comprised the first test lot of cold drawn steel cartridge cases which *all* withstood proof-firing without cracking, and *all* extracted satisfactorily. These early cases were made from steel plate taken from stock, drawn into a deep cup, tapered and trimmed. In order to use some thin plate that was available, a disk of metal was spot welded to the base to thicken it and machined properly for an extraction flange.

This work, as well as that by Corcoran-Brown Lamp Division of Electric Auto-Lite Co. in Cincinnati, showed it was possible to produce cold drawn steel cases from a cold disk or blank, by a number of cupping operations, ironing and drawing out the side walls approximately the same as is done in the manufacture of brass cases. That became the "standard" method for drawing steel cases, used with minor variations in later production by all except three of the American producers.

As far as the Norris Co. is concerned, a comprehensive engineering, metallurgical, and manufacturing program has been carried out on steel since mid-1941. This work has led to a sound system and data for the design of cartridge cases and gun chambers — not yet released — modification of at least one breech mechanism, a manufacturing procedure *which works*, and over 5,500,000 accepted 3-in. anti-aircraft steel cartridge cases. Full production has been continued after the Army Ordnance Dept.'s decision early in January of 1944 to stop production of steel cases in most calibers and in most plants, the supply of the more easily worked cartridge brass having become sufficient for anticipated war-time needs.

Although the manufacture of steel cartridge cases was generally stopped early in 1944, the Norris Co. was so successful that it has remained in full production, and in May the author, Fred Arnold, and two associates, Harry F. Ehrich, chief engineer, and John A. Kingston, factory manager, as well as Harlan A. Messner of Ohio Crankshaft Co., were given by the Army Ordnance Department the rare Civilian Citation for Distinguished Service in the production of 3-in. steel cartridge cases used by the Army in its anti-aircraft and anti-tank fighting on all fronts. This article is a resume of cartridge requirements and how they have been met with plain carbon steel, cold drawn and differentially hardened.

The engineering work in our plant on case design has been done by Edmond M. Wagner, research engineer. He made a comprehensive stress analysis of artillery cartridge cases and the conditions to be met when a round is fired. This work showed that 75-mm. or 105-mm. cases, when made from steel, had to have a minimum yield strength of about 100,000 psi. This explained why earlier experimental steel cartridges invariably stuck in the guns when fired, if they were made from steels having a low yield strength.

This stress analysis would form the basis of an interesting story in itself, but it must now suffice to say that elastic and plastic movements obviously are largest when a minimum sized case is fired in a field gun with a light barrel whose breech chamber is at the large limit of manufacturing tolerance, *after* it is warm from rapid firing and therefore further expanded, and after it has been used enough for considerable enlargement of the breech from scour and flame erosion. When the powder explodes in a metal case of any kind its diameter expands almost instantaneously until it smacks the inner walls of the gun chamber. The gun itself then takes the load and expands, elastically, the cartridge with it; total elongation in a circumferential direction exceeds 1.5%. The pressure also forces the base back against the breech block, and the breech block springs back to the limits of all its clearances *plus* its elastic strain. If there is undue motion here the case elongates permanently and it is difficult to slide the breech block aside.

When the pressure wave passes its peak gun tube, breech mechanism, and cartridge spring back, very rapidly. Now here's the critical point. The gun has not been overstressed, but the empty cartridge has been. Yet it must contract as much as the chamber *plus* enough (infinitesimal though it may be in amount) to free it from end to end and allow it to slip out readily after the round is fired.* Likewise the recoil of the breech block itself smacks the head of the cartridge case while it is still tight against the chamber walls. If the case is not strong enough this action will upset and bulge the lower sidewall, wedging it tight in the breech chamber.

An easy way of explaining the matter (although it is really much more recondite) is to remember that cold drawn brass whose apparent elastic limit is 45,000 psi. and whose modulus of elasticity is 12,250,000 psi. will have sufficient springback. Therefore steel whose modulus is 29,000,000 psi. must have an elastic limit of

$$\frac{29{,}000{,}000}{12{,}250{,}000}\ 45{,}000 \text{ or } 106{,}000 \text{ psi.}$$

to spring back a similar degree. This checks the early work at Frankford Arsenal, which found that "stickers" in 75 and 105-mm. guns had elastic limits of 90,000 psi. max., whereas extractable cartridges had 115,000 psi. min. It does no good to thicken the wall of the cartridge, for the powder will expand thick or thin wall alike out to the gun chamber, and the resulting stress depends only on the strain (unit expansion).

*It is our opinion that the surface coatings on cartridges, either intentional or non-intentional, have a good deal to do with free extraction. For example, a bare steel case may "freeze" to a clean steel chamber, whereas a chemical coating would prevent metal-to-metal contact and incipient welding. Likewise, it is easy to make a "sticker" out of a good brass case by washing it in ether.

The problem therefore was to start with a steel soft enough to be workable, and end up with it in such condition that it would have a correct (and high) elastic limit or yield strength. Of the two ways of raising the yield strength of steel, namely, cold drawing or heat treating, cold drawing was the most logical approach for a cartridge case manufacturer, since that is the way the required properties are induced in the conventional brass case. As a matter of fact, every design and size of case is a separate design and manufacturing problem. As will appear in the sequel, Norris Stamping and Mfg. Co. achieved success in 3-in. anti-aircraft cases of steel by a *combination* of cold work and localized quench hardening. We have been in full production for many months on 3-in. anti-aircraft cases for the Army. In the aggregate over 5,500,000 have been accepted. These cases are heat treated in the lower sidewalls, and we believe that heat treated steel cartridge cases, with proper surface protection, will meet more types of service conditions than brass cases. For some sizes and guns with high firing pressures, heat treated steel cartridge cases are mandatory.

Thus we have achieved the main objective of the steel cartridge case program aside from the conservation of copper, namely, the production of a *better* case than can be made of brass. I will now endeavor to show how this has been done.

Up to the point of heat treatment, the steel cases are made by cold drawing. These operations, shown in Fig. 1, are similar to those used in brass cartridge case manufacture, which have been described in the technical literature so frequently that they need no further space. They are a pre-cup, a cup, then four draws with appropriate process anneals after the cup, first, second and third draws. The metal specification calls for the following on check analysis: Carbon 0.24 to 0.34%, manganese 0.55 to 0.85%, phosphorus 0.040% max., sulphur 0.045% max., silicon 0.10% max. The steel is aluminum killed and spheroidized, the latter being necessary to permit cupping of the blanks, which is the most severe mechanical operation. We receive the steel as disks, or as plate from which we blank the round disks. When the steel company furnishes us the disks it is said a yield of only 50% of blanks is secured, based on the weight of the plate. When we do the blanking we get 70 to 76% yield.

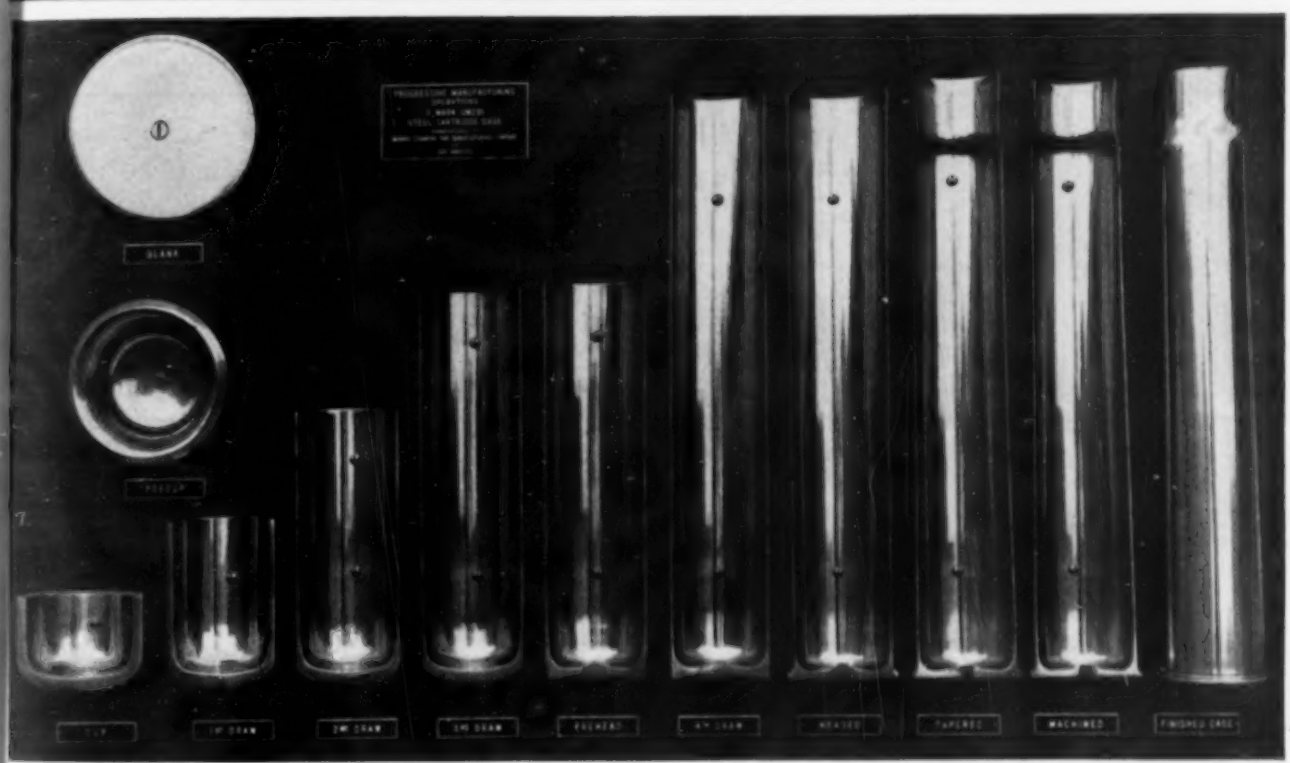


Fig. 1 — Progressive Manufacturing Operations on 3-In. Mark IIM2B1 Steel Cartridge Case, Heat Treated in Condition Marked "Headed"

Our scrap losses in the cold drawing operations have been low. From the beginning of our experimental production until the present, our

total overall rejects have been under 8% for all causes. It is currently running under 3%, but it must be said that this is still high when compared to our brass case lines.

The steel companies have done an excellent job of supplying us with good quality, uniform steel. From a metallurgical standpoint, experience shows that practically every steel disk will make a good cartridge case. Rejections of disks are almost exclusively for mechanical defects, such as sharp scratches or scores, loosely classified as "mill lines". These cause the steel to split open when cupped, with consequent damage to the tools. See Fig. 2.

To prevent this the disks are inspected and defectives rejected — or, if scratches are minor, they are polished out. It was found that if the disks were going to break they would do so by the time the cup was only partially formed around the nose of the punch; this is the reason for our pre-cupping operation. The parts are re-inspected for surface defects, and rejections have averaged about 3%. Improved salvaging methods are now reducing the actual loss of steel to a very low number (0.4% in November, 1944.)

Subsequent drawing operations constitute a very severe test of the quality of the steel. In some draws there are reductions in wall thickness up to 45%, yet it is very exceptional for a piece to break while being drawn. We consider that any case which has successfully withstood these five draws contains no hidden defects; from there on practically all failures are due to faulty processing. Some pieces do pull apart in the draws, however. These failures are caused by embrittlement by hydrogen, picked up from the acid when pickling off the annealing scale. This can be completely eliminated by proper additions of inhibitors. An epidemic of breakage is never traceable to the steel, but usually to insufficient inhibitor.

The tapering operation was the second greatest source of loss. We have worked this down to one-fifth of its former amount by greater care in applying and drying the lubricant, and inspecting the mouths for nicks and other irregularities before tapering.

When it was demonstrated that cold drawn 3-in. IIM2B1 steel cartridge cases with 95,000 psi yield strength were marginal for some of the guns in service, we decided to heat treat the cases to increase their yield strength at the region where trouble apparently resided. By measurement of fired 3-in. A.A. cases, it was determined that all cases, brass or steel, after firing were permanently expanded to the size of the gun chamber only in the lower sidewall for about 3 in. above the flange on the base. It was believed that if these 3 in. of lower side wall were heat treated to have a yield strength of about 125,000 psi., the elastic recovery would be sufficiently increased to meet all the requirements for extraction and ejection after firing, with a sufficient margin of safety.

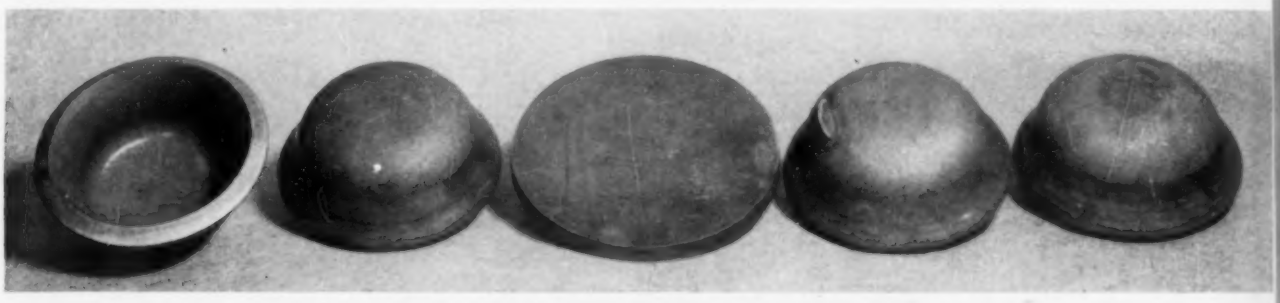


Fig. 2 — At Left Are Normal Pieces After Pre-Cupping, Inside and Outside Views. Next is a disk with the type of surface defect that leads to the failures shown in the other two

There are several advantages in heat treating only a short band above the base. The physical properties in other parts of the case are adequate for the service and these remain unchanged. Furthermore, the base and flange, already difficult to machine, are not increased in hardness. Again, cold drawn cases were in full production, and the flow sheet only required us to insert a hardening operation after the cases were headed. The sidewalls are then straight. As compared with a fixture for quenching the entire case, the design of the heat treating equipment for hardening a portion of this straight-walled tube is simple. By heat treating before tapering, no re-sizing operation is necessary. The stress relieving temperature of 750° F., required for the cold worked portion of the case, is also correct for the hardened section. The machining operations are in

no way affected, and distortion is no factor — as it would be were the case heat treated after tapering and machining.

The outstanding method for heating localized areas, such as this portion of the cartridge case sidewall, is by high frequency electricity. We already had in operation two 75-kw. Tocco Jr., 9600-cycle, high frequency units, built by the Ohio Crankshaft Co. This equipment is very useful and adaptable for developing processes involving heat. As is well known, work to be heated is brought within the influence of a magnetic field produced by an inductor coil which is quickly and easily built up by copper tubing silver soldered, or from copper forgings. Intensive work was therefore started on pilot lots of heat treated cases. One of these Tocco units was used as a source of power.

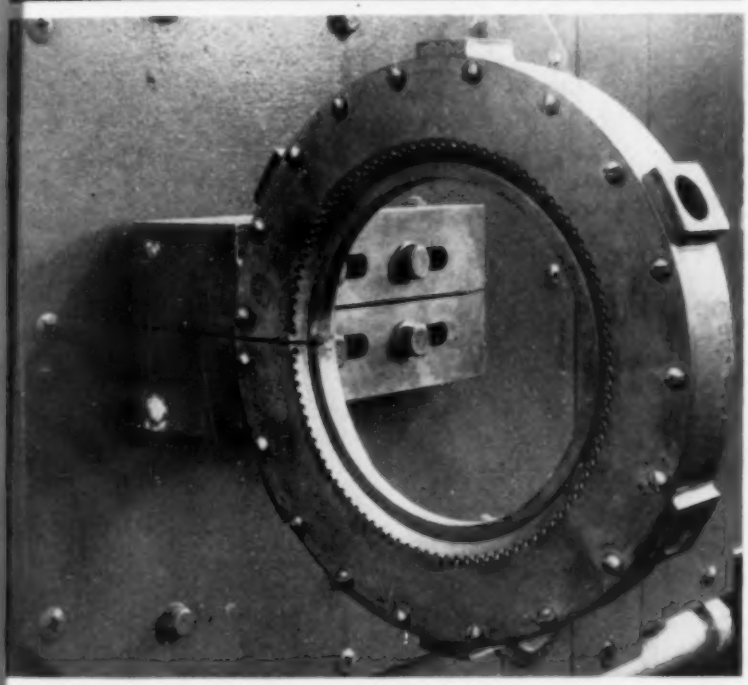


Fig. 3 — Front of Heating Coil; Note Quench Spray Outlets

The special problem in heating this portion of the cartridge case is a variable wall section which must be heated to a uniform quenching temperature. A cross section through the sidewall and head is shown in actual size in Fig. 6, page 74. We determined that it was impractical to heat the whole 3-in. long section at once, using a solid inductor, but instead a single-turn coil of the proper form was developed. This copper forging is shown in Fig. 3.

The narrow section, close to the case, concentrates the magnetic flux in a small band around the case. Heating the 3-in. length of wall section is accomplished by moving the case through the coil at the proper rate. In order to provide the necessary cooling and quenching water passages, the section of the fixture surrounding the electrical conductor must be considerably enlarged.

The cases are quenched by a strong water spray, delivered through two rows of $\frac{1}{16}$-in. orifices, drilled at 30° to the axis, directing the water to a point about 1 in. away from the face of the coil. A more oblique angle causes a backwash. Coils bolt directly on the transformer terminals and carry 100 kw. of power. In their present form they are very effective.

When we had developed a coil which worked satisfactorily, we used a simple hand-operated fixture to hold and move the case while heating and quenching, and several sample lots were made. These withstood proof firing to the satisfaction of all concerned. The success of the method was demonstrated.

Mention should be given of the outstanding effort made by everyone who was working on this project — the laboratory staff that coordinated the work, the engineering department, machine shop and workers generally throughout our organization. Throughout all this development we were greatly assisted by the advice and suggestions of Harlan A. Messner, the Pacific Coast engineer for the Ohio Crankshaft Co.

Heat Treating Fixtures

Since production of heat treated cases was to start at the earliest possible moment, three more 100-kw. machines had to be purchased and installed, together with auxiliary equipment such as a large quenching water system and pumps.

Our engineering department designed and built six fixtures to position and move the case in relation to the coil during heating and quenching. Its components are a carriage, a locating arm, a motor drive with positive clutch, and a cam. The carriage is a semi-cylindrical bronze casting which fits and holds the case while it is clamped in position by an upper shoe, magnetically operated. All this is hid behind the motor bracket in the illustrations.

The locating arm is fastened to the carriage, and is shown protruding in Fig. 4. It serves

three purposes: The large cone prevents the case from striking the coil while being loaded. Its nose positions the case, in relation to the coil, from the inside surface of the base. This determines where the heat treated zone starts, and is thus independent of variations in base thickness or trim length. The rod carrying the nose travels ⅛ in. and closes a micro-switch in the power circuit before the case is clamped in place. This is one of the fundamental safety features built into the circuit: If the case is not properly positioned in relation to the coil, so that the heat treated zone starts and stops at exactly the right position, the power cannot come on.

Figure 5 shows the carriage assembly being loaded in the "out" position. It rides on rails; the surrounding heating coil is stationary. The carriage is pulled to "in" position by a counterweight so that when heating starts, the end is ½ in. from the coil. This motion is very rapid, and is cushioned by an oil dashpot. Meanwhile the lucite hood shown above the operator's hand in Fig. 5 is lowered to contain splash from the quenching sprays.

A cam, driving against the counterweigh now moves the case back through the coil. Th cam is chain driven by a ¼-hp. motor constantl rotating. The clutch on this motor is a ver critical part of the assembly. The whole schem of the operation is based on constant rotation o the cam, in time with an Eagle Signal Co. synchronous program timer.

When the operator hits the "start" button it simultaneously starts the timer and actuate the clutch. If the clutch should slip the least bit it would put the program out of time. Good free wheeling clutches were tried unsuccessfully. Double-acting Pullmore disk clutches are now used, modified by introducing serrated plates on the drive side.

The cam itself was developed largely by trial and error, and while it rotates at constant speed, a little slippage here and there had to be eliminated. It moves the case for about 4 in.; power at full output is on for about 3¼ in. of this travel, and the rate must be adjusted so the temperature of the wall (varying in this short distance from $\frac{3}{16}$ in. thick near the base to $\frac{1}{16}$ in. up the side-

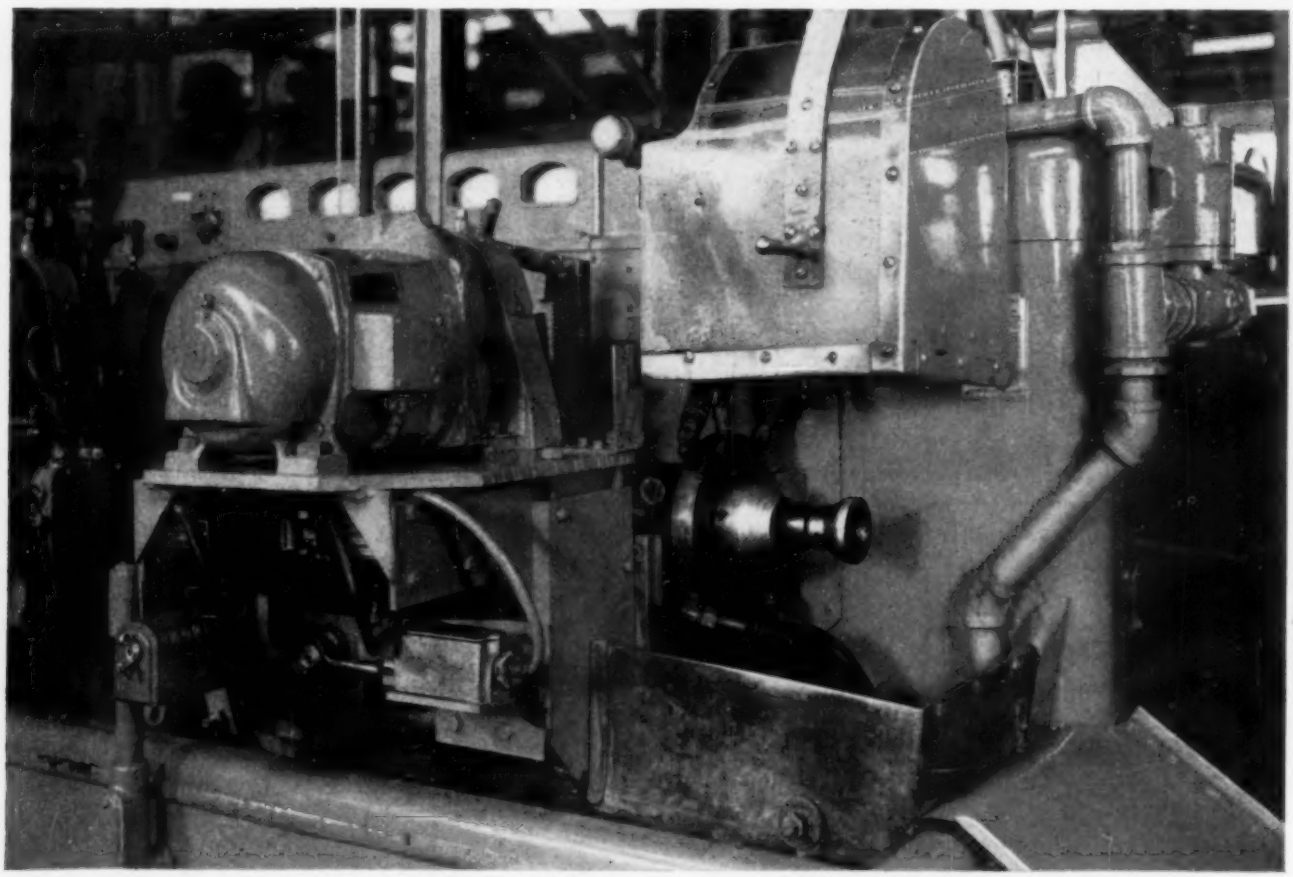


Fig. 4 — Heat Treating Station. Note heating coil directly ahead of motor bracket, inner cone to guide the case up to the coil and locating nose at right of cone

wall) reaches uniform temperature, 1800° F. If for any reason the carriage is delayed beyond one second in placing the case properly in the coil, an electronic timer prevents any heating whatever. The carriage does not start to move forward for about 3 sec., thus putting a lot of heat into the wall near the base. To overcome the strong preheating effect on the adjoining upper wall, the cam then moves the case ahead rapidly, giving it almost a ⅜-in. jump. By this time the preheating pattern in that portion of the wall entering the coil is well established, so the cam is developed to move the case at an accelerating rate as it decreases in thickness.

After the case has moved out about 1 in., the quench water comes on and continues on through to the end of the cycle. Jets impinge about 1 in. away from the coil. Since our cartridge cases are made from plain carbon steel (0.29% C), it requires drastic water quenching to harden. Only heats with both carbon and manganese on the low limits fail to harden to Rockwell C-50 minimum.

The power is on for 9 sec. and shuts off automatically after 3¼ in. of the case sidewall has been heated.

This heat treating procedure inevitably produces two annealed bands in the case, one close to the base, and one about 3½ in. up the wall (see Fig. 6, page 74). These are only about ⅛ in. wide, and cause no trouble. The one at the base is below the area of maximum bulge found in the fired cases; the one up the sidewall stretches slightly on firing but does not grip into the gun chamber.

Water requirements for cooling and quenching, when three machines are operating simultaneously, are about 400 gal. per min. of quench time. Water is pumped from a 1200-gal. settling tank at 135 psi. through a filter to the quench manifold. There are six inlets to each coil. Pressure in the coil at the time of quenching is about 45 psi. The water is re-used once, by bleeding about half of the used water over an adjustable weir into the sewer and automatically mixing new cold water with the balance in the sump. The quenching water temperature is kept below 83° F.

After the case is drawn with parallel sides, the mouth is about Rockwell B-98 and must be annealed so it can be tapered. For this operation we consider the Tocco Jr. high frequency equipment ideal for putting in the production lines, and two 75-kw. machines were purchased. One is used to soften 4 in. of the sidewall below the mouth. The cases are placed in either one of a pair of helical coils and heated to 1100° F. in 2.7 sec. — a production rate of 1000 per hr. This annealing drops the mouth hardness to B-70, and eliminates splitting in tapering.

The tapering operation work-hardens the mouth again to Rockwell B-95. The second machine further down the production line, with an almost identical setup, re-anneals the mouth and shoulder at 1250° to B-75, soft enough to permit crimping the case on the projectile, and obturation when the round is fired.

These operations are not entirely trouble-free. A trained electrician and supervisor are in constant attendance on all shifts to keep the process always up to standard. A station is stopped, immediately, when trouble develops.

It is difficult to imagine more exacting service requirements than those to be met by a cartridge case. It must withstand an impact pressure of 38,000 psi. (service pressure), expand with the gun, and recover sufficiently to extract

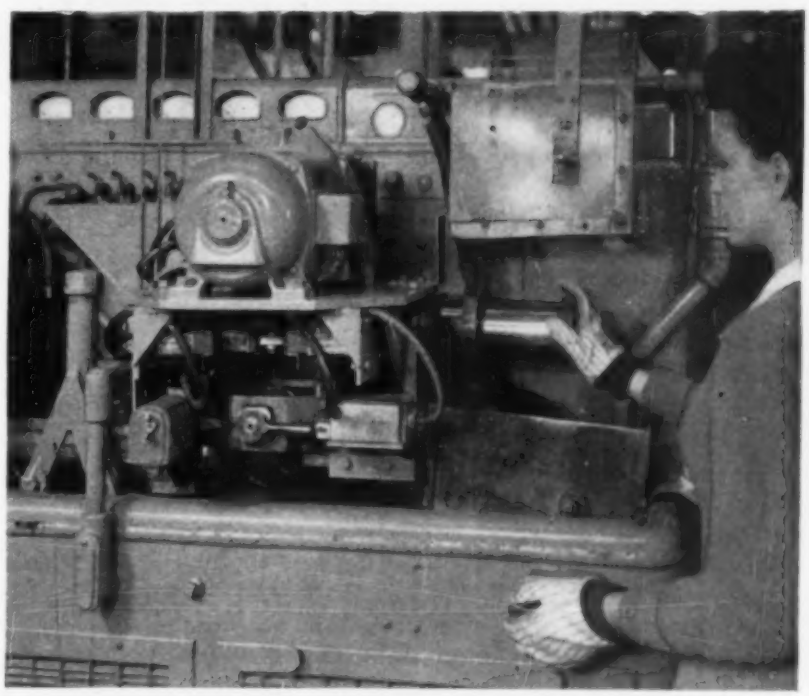


Fig. 5 — Operator Is Loading a Case Into the Heat Treating Fixture. Starter button, under her left hand, also operates the gripper and starts the cycle. Hood above is pulled down to avoid splash of quenching water

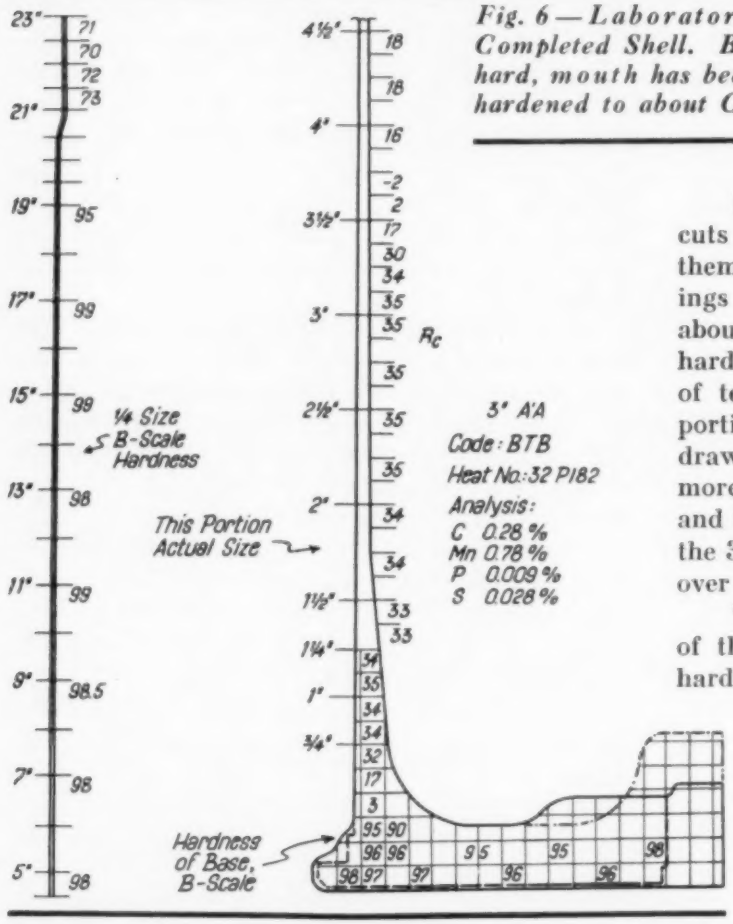


Fig. 6 — Laboratory Record of Hardness Explorations of Completed Shell. Base and most of sidewall are medium hard, mouth has been annealed, and sidewall near base hardened to about C-34. Note soft spot 3½ in. from base

Besides the shop inspections, the laboratory cuts apart cases on a 24-hr. program, and explores them for Rockwell hardness, recording their findings on charts as in Fig. 6. More information about the cases and the processing is obtained by hardness explorations than by any other method of testing. Average hardnesses of the various portions of the case are as shown. The cold drawn sidewall and base usually do not vary more than one point on the Rockwell "B" scale, and the heat treated zone between the ¾-in. and the 3¼-in. stations three points on the "C" scale, over or under the values shown.

These laboratory tests check the functioning of the following equipment as reflected in the hardness of the case: *(a)* The individual Tocco station on which it was hardened. *(b)* The stress relief oven in which it was stress relieved. (This is the primary reason for making the test — to insure proper stress relief.) *(c)* The individual Tocco mouth anneal station. *(d)* The heading operation — flow of metal and inspection of the radius. *(e)* The response to the heat treatment of the particular heat of steel. *(f)* Hardness of the cold drawn portion of the sidewall. *(g)* The location of the heat treated zone and position of the annealed bands.

and eject. The test of a good cartridge case is the ability to re-chamber it after firing. As service pressures continue to be raised, only heat treated steel cases can meet the demand on many sizes. On the other hand, a soft case will certainly stick in the gun, possibly putting it out of commission in a critical moment.

With this possibility before us, we are determined that no sub-standard case shall get out of the heat treating department. Besides building safety features into the electrical circuits of the heat treating equipment which prevent soft cases from being made, John Isaacs, assistant metallurgist, designed and built a magnetic tester through which all cases pass. It will reject any case lower than standard hardness, being sensitive enough to reject decarburized cases merely because their average hardness is too low.

Our combined inspection procedure has been so effective that in recent months 2,000,000 have been accepted by means of proof-firing over 4000 of them selected at random at 112% of service pressure. There was not a single malfunction in this entire run. This is one instance where there is no middle ground. Nothing short of perfection suffices.

STRESS-CORROSION CRACKING OF METALS

A summary, by a participating metallurgist, of important topics discussed during a three-day symposium sponsored by the American Society for Testing Materials and the American Institute of Mining and Metallurgical Engineers, held in Philadelphia late in November.

IT HAS BEEN WELL KNOWN for many years that stressed brass will crack when placed in contact with atmospheres containing ammonia, frequently without indications of even moderate general surface corrosion. It has more recently been discovered that, with a suitable choice of corrodent and stress, alloys of iron, nickel, aluminum, magnesium, lead and even gold can be made to crack in a similar manner. Many experts expressed the opinion at the symposium being reported that with a little ingenuity methods can be found to make *any* metal "stress-corrosion crack". One paper demonstrated that the possibilities in this direction are not confined solely to the metals but may include the plastics!

Such observations tend to create the impression that stress-corrosion cracking is a major source of service failure. Many speakers, including the symposium's summarizer, emphasized that — while the problem of controlling this phenomenon is real — the amount of known service damage is comparatively small. The ever present threat of a disastrous series of failures, particularly in war material, amply justifies the careful attention being given to the problem. Only when complete understanding and control of the essential factors have been achieved can this threat be dissolved. It was clear from the intense interest (and "intense" is not too strong a word) shown in the papers and discussion that technical men do not intend to stop short of this goal.

Other Forms of Stress Failure — While the name of the present phenomenon is virtually self explanatory, some confusion still arises between stress-corrosion cracking and other forms of stress failure. This was clearly brought out in at least one paper which called attention to the fact that a specimen loaded to near its yield point may fail by simple fracture if the corroding environment can cause sufficient reduction in section thickness to raise the unit stress to the rupture level. If the rate of surface corrosion is increased by the stress, as frequently happens, the possibility of such an occurrence, through wasting away, is increased.

Corrosion Fatigue, which combines stress and corrosion with a crack-type failure, may be closely related to simple stress-corrosion cracking but this has not been demonstrated. In many cases it was indicated that stress-corrosion cracking only initiated the failure, the final break occurring by simple rupture. Apparently, clear thinking and a careful analysis of the known facts are essential to any examination of reputed stress-corrosion failures in service.

Stresses

While stress is one of the essential requirements for stress-corrosion cracking, definition of the type and magnitude of the stress has proved difficult. All of the authors and discussers at this notable gathering agreed that tensile and not compressive stresses are involved, but no one seemed entirely certain about the exact nature of the stresses. Many laboratory tests were reported in which the stress was applied by external loadings of various kinds. Frequently the applied stresses were at the level of the yield point of the metal in the tested condition. In other instances the stress was fixed at some, usually high, percentage of the yield stress.

Since there was much evidence that, under some conditions at least, stresses of yield point intensity are required for failure (this was shown to be true for the mercury cracking of brass, for example) there was considerable criticism of certain results based solely on high stresses. It would seem necessary for the investigator to determine a stress versus time-to-failure curve for a given metal in a given environment to determine the possible existence of a threshold stress below which no failure would occur. Such determinations have been made for a few metals. Annealed brass in an ammonia atmosphere shows a threshold value at a stress of about 2000 psi., while cold worked brass shows none — even when the stresses are carried to the very low figure of 500 psi. Incomplete data from tests of austenitic stainless steels in magnesium chloride solutions indicate a threshold stress for annealed metal at about the yield point, and it appears to lie at about one-third the yield stress in such steels cold rolled.

The problem of stress evaluation becomes very complicated when considering internal or locked-up stresses derived from fabrication. Various papers presented attempts to evaluate them by the split ring, X-ray and other methods. The apparently more drastic failures in plastically deformed objects as compared with externally stressed pieces offer an interesting field for conjecture. The interplay of multi-axial stresses, and the possibility expressed by the symposium summarizer that microstresses of very high magnitude may exist in plastically deformed articles, seem to this reporter to deserve a considerable amount of attention. It does not appear possible to evaluate properly the threat of service failure until the stresses to be encountered are understood. Perhaps even the final understanding of the basic causes of stress-corrosion cracking awaits this evaluation.

Corrosive Environments

While considerable progress has been made in recent years in the discovery and control of various laboratory corrodents, much remains to be learned of the specific service environments in which failure can occur. In the case of brass it has long been known that stress-corrosion cracking will occur when stressed articles are placed in service in atmospheres containing even traces of ammonia. Nitrogen oxide must now be added as an additional possible cause of service failure. Two failures were reported of stainless steel coffee pot lids. In view of the thousands of similar lids of supposedly very similar types which did not fail in service one wonders what could have been different about these two. We have sampled restaurant coffee which was capable of eating holes in almost any material, but surely there are more than two such places.

Prevention

It was evident from the proceedings of this meeting that the metallurgist has given much attention to the problem of preventing stress-corrosion cracking. The most popular method is to reduce the stress level by low temperature anneals, usually just below the recrystallization temperature; for example 45 min. at 475° F. was suggested for brass. It was stated that 60 min. at 1000° F. would reduce the stresses in cold drawn nickel tubing to 50% of the original level, and annealing at 1200 removes 85% of the stress. Experience indicates that the lower temperature does a sufficient job and leaves the tube at a higher strength level. While stress relief anneals at 1375° F. were reported to have some value in Type 347 stainless, a better temperature is 1600.

Heat treatments to alter the structure of light metal alloys have been used. Where precipitates of compounds are encountered much can be done by controlling the location of the particles in the grain structure. Electrochemical studies have revealed potential differences which are believed to account for the effects noted.

Barrier protection, by which the metal surface is shielded from the corroding environment, has received increasing attention. Phenol formaldehyde films on brass and polybutene layers on lead were reported to be helpful. Undoubtedly other similar films will receive attention in the future. The use of layers of pure aluminum as claddings for susceptible aluminum alloys may be regarded as a type of barrier protection. However, such relatively thick coatings provide electrochemical protection also.

Prevention of stress-corrosion cracking by alloying occupied the attention of one laboratory. It was reported that the addition of about 1% of silicon to cartridge brass together with a quench following a 1475° F. anneal greatly increased the stress-cracking resistance of the brass to ammonia. This approach to the stress-corrosion cracking problem also seems to warrant attention.

Molten Metal Penetration

It has been known for a great many years that drawn brass cups and tubes will crack suddenly when placed in contact with mercury. A suitable anneal will reduce the internal stress to the point where no such cracking in mercury occurs. Other liquid metals will have the same effect on brass and other metals. For example, monel metal is affected by mercury if sufficiently stressed. One could compile a long list of occurrences. The interesting point involved, however, is the question of whether such stress cracking in mercury bears any fundamental relationship to stress-corrosion cracking.

Working with single crystals of brass and with polycrystalline pieces produced from them, one author showed clearly that while ammonia could penetrate the stressed grains when no boundaries were available mercury could penetrate only along grain boundaries. It was therefore concluded that the two mechanisms must be different.

Electrochemical Nature of Stress-Corrosion Cracking

The work of the past several years has resulted in a better understanding of the fundamental nature of the stress-corrosion cracking phenomenon. A general theory was advanced at the symposium based on the considerable evidence that the reaction is electrochemical in nature. For example, it was shown that the grain boundaries of coarse-grained cartridge brass are anodic to the grains when exposed to ammoniacal solutions. Confirmation was obtained when stressed brass tubes which cracked severely in ammonia in five days were removed from such solutions undamaged at the end of 14 days when a cathodic potential of 10 volts was applied.

In another set of experiments, the potential differences between the grains and the grain boundaries of a quenched aluminum alloy containing 4% of copper were observed over a period of time in a solution of sodium chloride in hydrogen peroxide. During the first 8 hr. the difference (boundaries anodic) increased. After 8 hr. the difference decreased, reaching practically zero at the end of 32 hr. Stress-corrosion tests under similar conditions confirmed that the rise in potential difference was accompanied by an increase in stress-corrosion cracking while the fall in the potential difference to zero paralleled a decrease in cracking to zero. The potential changes were also found to be explainable in terms of the microstructure, the earlier increase accompanying the precipitation of the copper as a compound in the grain boundaries, and the final return to zero potential difference resulting from the complete precipitation of the copper throughout the whole structure.

The authors of this paper discuss the role of stress in interesting fashion. They pictured the stress as providing a means for tearing open grain boundaries already weakened by corrosion. They postulate that the tearing action exposes fresh, uncorroded metal to the corrodent. Since fresh surfaces of this type are more anodic than corroded areas an acceleration of the localized attack results. They did not consider the possibility that the difference in potential between the grains and their boundaries may be directly influenced by the stress.

Notes on Individual Metals

In the above summary of the broader aspects of the stress-corrosion cracking problem many interesting details specific to a particular metal were necessarily omitted. These will now be covered so far as space permits.

Brass — The time honored mercury test for brass apparently has been relegated to the background as a laboratory tool in favor of the ammonia test. As a testing tool it still is used, since it provides a means of determining whether the internal stresses in a fabricated part are too high. It was indicated in several papers, however, that articles which pass the mercury test may still fail in the ammonia test or in service. In addition to being a more searching test, the ammonia test can detect stresses of relatively low magnitude (failures have been obtained in cold rolled brass with applied stresses as low as 500 psi.).

Considerable attention has been paid to the development of controlled ammonia tests. Two authors worked out procedures using the atmospheres over aqua ammonia. Another laboratory developed an apparatus which permits 16 specimens to be exposed at one time in an atmosphere containing air, ammonia, water vapor and carbon dioxide (water vapor high but below saturation). The stresses were applied externally by dead weight loading. Provision was made for changing

specimens with minimum dilution of the test atmosphere. The authors developed the interesting point that in the absence of carbon dioxide the failure of brass took place very slowly. Possibly someone will carry such tests to the complete removal of carbon dioxide and find that no failure occurs.

Using the ring method it was demonstrated that sections cut from cartridge cases have only very small internal stresses. Other workers found high stresses in these walls before the sections were cut and demonstrated that compressive stresses in the thick head section were responsible for tensile stresses in the wall. These same workers showed that the stress level in cartridge cases can be varied by varying the tool design.

Cartridge brass of extreme purity was found to fail in the ammonia test just as rapidly as brass of commercial purity. One laboratory reported a comprehensive study of the influence of a large number of elements on the stress-corrosion cracking resistance of brass. No element was found which accelerated cracking. Several were noted to decrease cracking, but most of these were effective only when the alloy was rolled in a non-commercial manner. The most effective addition is silicon in the amount of about 1%, and the protection was greatly increased when the silicon brass was annealed at 1475° F. and quenched.

One important paper reported mercury stress-cracking tests on pure copper, five binary brasses, two leaded brasses, one copper-silicon alloy, two tin bronzes, and two nickel-silvers. In each material two or more tempers were included. Tests were made with the grain, across the grain and at 45° to the rolling direction. In all but three cases no cracking occurred until the stress had reached the yield point (measured at 0.01% offset), and in these three cases failure occurred above the *proportional* limit. The authors called attention to the fact that in their many years' experience they had never encountered a service failure in flat brass spring parts unless the stress was above the yield point. On the other hand, many failures had been seen in parts containing internal stresses resulting from drastic fabrication operations.

Aluminum and Magnesium — Development of laboratory test methods for evaluating the stress-corrosion resistance of the light metals and alloys has proceeded along rather different lines than in the case of brass. Various aqueous solutions have been and are being tried. All workers seem to agree that any laboratory test to be acceptable must duplicate the results of atmospheric exposures under dead weight loading.

Magnesium is being studied intensively because of the ever present desire of the airplane industry to design to higher and higher stresses. Much the same is true for the aluminum alloys but the longer background of experience with these metals perhaps eases the pressure somewhat. It has been pointed out that the creep characteristics of the magnesium present a complication in planning beam type tests. Also the fact that the compressive yield strength is lower than the tensile yield throws the axis of zero stress toward the tension side and away from its calculated position. Generally speaking, beam tests aimed at constant strain are likely to be at lower stresses than those calculated.

The salt spray test is regarded as relatively dependable for evaluating the resistance of aluminum alloys to stress-corrosion cracking in marine locations. It acts very slowly, however, and is not particularly useful where comparisons with normal atmospheric effects are desired. Each type of aluminum alloy seems to have a preferred testing solution. For example, the aluminum-copper alloys are tested in a solution of sodium chloride in hydrogen peroxide, while the aluminum-zinc-magnesium-copper alloys require a boiling sodium chloride solution. Special tests have been evolved in which the corroding solution contains chromates or dichromates. The general attack on the surface is very small.

Various means are used to stress the aluminum alloys in test. Unlike magnesium, aluminum does not creep under stress in constant deflection tests. Many interesting modifications of the simple beam test have been used. Internal or locked up stresses are also investigated by drawing partial Olsen cups.

Miscellaneous Metals — The information reported for nickel and lead involved no special laboratory environments. The nickel data all were from case histories of service failures. The lead was tested in the laboratory atmosphere. The failure of optical parts made of low carat gold was again a case history and did not reveal the specific corrodent.

QUALITY STEELS--
TODAY & TOMORROW

Two papers from
group meetings at
National Convention

Present Steelmaking Processes

By Earle C. Smith
Chief Metallurgist
Republic Steel Corp.

AS OF JANUARY 1, 1944, the American Iron & Steel Institute reports the capacity of the American steel industry as follows:

Openhearth	82,223,610 net tons
Bessemer	6,074,000
Electric	5,350,880

In 1943 the Industry made 78,621,804 net tons of openhearth steel, representing 98.9% of the potential capacity; the bessemer production was 5,625,492 net tons, or 89.1% of capacity; and the electric furnace steel make was 4,589,070 net tons, 96.7% of capacity. (Bessemer production means ingots, and does not include blown metal for feeding openhearths or electrics.)

This war operation was probably the peak ability of this nation to produce steel in its present facilities. The war's requirements certainly influenced the type of steel manufactured, as evidenced by the pre-war consumption of electric furnace steel which was usually well below 1,000,000 net tons per year. Neither did the bessemer process approach its operating capacity in spite of pre-war pressure to use it where it was usable.

Why did this pattern of production exist?

A short description of the producing units will serve as a foundation for the comparison of their usefulness.

The oldest tonnage process is the bessemer, in which steel is made by blowing air through molten metal. Its present production unit, the converter, is a pear-shaped vessel with a perforated bottom; the vessel may be rotated about trunnions and air is conveyed by blast pipe to the bottom of the vessel and discharged through the molten iron. The process is quick and adaptable, but has the limitation that the steel produced from the usual American acid-lined vessel is high in phosphorus and nitrogen, and generally high in sulphur. Acid bessemer steel is excellent for fire welding. With added sulphur it is especially good free machining steel, being the standard material for automatic screw machines. Its European form, producing basic bessemer steel, differs in that it is carried out in a basic lined vessel with a two-slag operation, the last slag being a sand-lime slag which removes phosphorus and sulphur. Basic bessemer steel is the European standard tonnage steel for ordinary use.

The openhearth was an invention that arose out of an experiment where iron was melted in a glass furnace. The original operation was in a sand lined (or acid) furnace; the product was only as pure in phosphorus and sulphur as the raw material, as neither was removed. With

wood chips for fuel in the gas producer, and electric furnace pig iron having less than 0.01% phosphorus and sulphur, Swedish acid openhearth steel made today is the equal of any generally found in the world, made by any process.

The basic openhearth solved the problem of high phosphorus and sulphur in the raw material. It is true that there are limits, but these are in economics rather than in metallurgy. With present available raw material, it is the most effective tool in the world's steel industry, especially so in the United States and Russia, two nations with iron ore resources relatively low in phosphorus. The magnesite or dolomite bottom, the lime slag, the variable charge from 100% iron to 100% scrap, with carbon, all transform the raw material problem into one of the desired end quality, which in turn determines the economic limitations.

Openhearth Alloy Steels

The basic openhearth will compete with bessemer in the field of the simple products, commodities such as fence wire, structural steel, roofing sheets. It will readily make rail steel and heat treating carbon steels of the simpler varieties. It can also produce heat treating carbon steels of the most critical qualities, as well as alloy steels for about all the present requirements — including guns and airplane engines.

This great flexibility of the basic openhearth has made it difficult to determine exactly how to differentiate the qualities which have their origin in this furnace. For instance, cold heading bolt stock for a simple machine may have a chemical composition identical with that of cold headed bolts for an airplane engine. The former is "ordinary" steel; the latter is subjected to rigid specifications and close inspection. The difference may be entirely in the physical quality of the finished product.

Openhearth steel is ordinarily thought of as carbon steel. The current war saw an increase in general steelmaking of less than 30%, yet basic openhearth *alloy* steel increased about 400% in quantity. The reason for this increase was that the furnace and melting skill were available. War demand handled the rest. The country was combed for scrap and the return scrap incidental to war was sent to steel plants. The better portions of the country scrap went to openhearth alloy steels along with the returning alloy scrap. Without the basic openhearth and its ability to absorb this in its charges the munitions program would have stopped in the early stages.

Since there was available but one-third the electric furnaces that would have been needed for high grade alloy steel, the openhearth took the load and delivered the steels. They were good steels. Even so, the whole industry was thrown out of balance because the making of munitions produced more alloy scrap than could be used in openhearth furnaces. The alloy scrap to and from peace-time automotive and machine manufacture about balances, but with the additional load of such scrap incidental to munitions (and it is nearly double) the openhearth falls down and the electric furnace must come to the rescue. This is one reason for the rapid expansion of electric furnace capacity since 1940.

When Heroult put a lid on Stassano's ore reducing furnace in 1900 and started making finishing slags, the electric steel industry was set and under way. The opposite extreme of production is where it ended. The electric furnace now uses practically all scrap and no ore. It produces the highest grade products and not the simplest steels. The electric is the furnace of the areas wherein are centered the highest development of skill in the *use* of steels. It is no longer a pioneering unit, but it is barely out of the development stage, and certainly is not a finished tool in its present embodiments. It can make about everything in the way of steel that civilized man uses. It can make compositions using oxidizable alloys with which no other process has a chance. It has the future to explore for its place in industry.

In the great list of steel compositions it is directly competitive with the basic openhearth by reason of lessened scrap in the stage of the finished article. Where the man-hours per unit of weight in the finished product are many times the unit value of the raw product, it is good sense to insure the end point by purchasing material with the best record of finished product. The electric furnace, properly handled, will usually have a record of finished part rejections traceable to furnace quality about half that expected from openhearth steel. It has the additional advantage that no rank outside heat with very high rejections is to be expected. To date the openhearth furnace still has to solve the problem of the occasional heat that produces many rejections for quality in spite of all possible metallurgical precautions; consequently the electric has the call when the results are vital and there is no time to replace rejected material. Aircraft bearing steels, vital combat engine parts, as well as cannons and guns which are really punished, are natural electric furnace products.

Now it is logical to use each tool at its best spot, and combinations of tools are in order and very sensible. Steelmakers therefore use combinations of steelmaking processes.

The first electric furnace in this country was fed hot metal from a small acid openhearth. Other early furnaces were supplied with molten steel to finish from a bessemer converter. A combination of bessemer, tilting basic openhearth, and electric made much of the early tonnage. Later, scrap melted in a cupola was fed directly to electrics and refined. The openhearth has been used to melt and refine poor scrap, and the steel, thus made, was poured into ingot molds, cooled and remelted in electrics. Lately much openhearth steel has been fed molten to the electric for finishing; this double-refined product is common in both Europe and the United States.

The question of *quality* of the respective combination processes naturally arises. It can be said that, in principle, there need be no difference in quality. Either the cold stock charge or the hot stock charge can, in many modifications and by proper manipulation and control, produce the same end product. The limiting factor in every case is the end quality required, combined with the skill and the knowledge of the producer.

For example, the conventional operation of an electric furnace to produce such a commodity as a combat engine crankshaft is about as follows: A charge of cold scrap is melted in the furnace, subjected to oxidizing conditions and certain impurities are removed. The slag from this operation is removed and a finishing slag is made to prepare the bath for alloys or such additions as are deemed essential.

If the job is done properly the end result is good. A hot metal charge from any convenient melter is only another way of starting, and this war has demonstrated again what was known in Europe and the United States that the steelmaker could combine many methods of steelmaking and end at the same quality standard.

The simplest of these combination operations is the cupola-electric layout. The next simplest feed for electrics is from the bessemer converter of a regular steel plant. Although the isolated bessemer fed from a cupola is under a handicap, even it can do the job so far as quality is concerned. The European combination of the basic bessemer and the basic electric is the fastest; single-slag heats in an hour, and two-slag heats in barely two hours, are regular operations there.

The use of stationary basic openhearths, while not convenient, is satisfactory from the viewpoint of the handling of the molten metal, a part of which must always be poured into ingots for remelting. The tilting basic openhearth is the handiest feeding unit; all the flexibility of process of the basic openhearth is retained; in fact the tilting basic furnace is much more adaptable to various raw materials than the conventional stationary unit. It is feasible and convenient to operate a tilting furnace with 100% hot metal from blast furnaces, making the entire steel production independent of the usual sources of scrap.

On both sides of the ocean are such plants combining blast furnace, tilting basic openhearths and electrics as integrated steel units. In one the whole cycle is present; there are blast furnaces, bessemers, tilting and stationary basic openhearths — also acid openhearths; there are electrics, arc, induction and in one case arc-induction

Tilting 185-Ton Openhearth in Kaiser Co.'s Fontana (Calif.) Iron & Steel Division — One of Six

furnaces. Every combination of primary production can be linked with any finishing method. The quality of steel made is a matter of the skill applied; alloy is saved, salvaged, and some combinations are practical that are otherwise difficult.

The matter of quality of product boils down to the statement: "Steelmaking is an art". Skill and experience are still the most important elements involved. The electric furnace is the most controllable unit for melting steel, and its products can therefore be of the highest quality available. Where cost of finished product exceeds the raw steel cost many times, the electric furnace is used to insure the end result. Combination schemes of production are perfectly controllable, and in time to come will make all the steels now commonly encountered.

Future Changes Reasonably to Be Expected

By H. B. Emerick
Steel Works Metallurgist
Jones & Laughlin Steel Corp.

ANY CONSIDERATION of the future of the industry should start with the problem of ore supplies and its influence on iron smelting.

In the United States, the iron blast furnace should remain the predominant metallurgical unit for the initial conversion of ore to metal for many years to come. Its operation, however, will be vitally affected by the tremendous demands made on the iron and steel industry during the past few years. Within the next decade we will all but exhaust the supply of high grade, easily mined ores. The future of the industry therefore depends upon the development of methods for producing high grade concentrates from the enormous quantities of low grade ores available. Beneficiation of these ores by crushing, screening, washing, or other methods designed to obtain high iron concentrates, will produce great quantities of fines at the concentrating plants. Recovery of the metallic iron present in extremely fine material of this sort, and the improvement of the structure of the concentrate, will undoubtedly require sintering or agglomeration by some o means; this situation should stimulate wider of sinter and other beneficiated materials in blast furnace burden with attendant operat advantages.

It is a safe prediction that blast furn operators will be continually under pressure fr the steel producing divisions to furnish iron uniformly low sulphur content, within a narr ing range of silicon content and physical te perature. Faced with the prospect of infer chemical and physical properties in raw ma rials, as well as inferior fuel, the blast furn operator will of necessity blend and size the or fluxes and coke in order to approach more clos ideal smelting conditions in the furnace sh

The industry is watching with considera interest current experiments aimed at the dir reduction of metallic iron from ores. As y however, there are no indications that any these low temperature gaseous reduction versio of the ancient sponge iron process will produ competitively and commercially, any tonnage.

Steelmaking — Prior to the present war t bessemer process was steadily losing ground the openhearth and electric furnace. Aside fr economic factors which operated against it, t bessemer sustained serious losses in its produc for a combination of metallurgical and mecha ical reasons. Higher contents of nitrogen, ph phorus — and perhaps oxygen — in bessem steel are believed to be largely responsible f many of the undesirable metallurgical characte istics which distinguish it from openhearth ste Intensive research is now in progress at sever points on adequate methods for controlling the critical elements and improving the properties the steel. Definite progress has already be made on the problem of phosphorus removal an a commercially feasible dephosphorizing meth is now in daily use by at least one large produce Satisfactory deoxidation, it has recently bee reported, follows the reaction of the carbon in molten pig recarburizer wherein most of the oxy gen in the steel is removed as gaseous carbo monoxide.

Interest has been revived in the possib merits of iron ore, or other oxide of iron, to co overheated metal in the vessel. Such an additio efficiently and economically reduces iron to th metallic state, with associated benefits in the wa of increased rate of oxidation of the metalloid increased metallic yield, and better control o temperature.

Inherent thermal and economical advantage associated with converter oxidation should con tinue to render the converter itself a valuab

adjunct to basic openhearth duplexing plants for years to come. Some expansion of electric furnace plant, duplexed with converters, may also be expected.

The recent development of million-volt X-ray equipment which can easily look through 5 in. of steel, and the expanding application of radiographic and magnaflux methods of sub-surface inspection, presage a period in which the basic openhearth steel producer, in order to improve the metallographic cleanliness of his product, will find it necessary to operate furnaces at temperatures appreciably higher than those in common use today. Temperature of the bath influences the elimination of non-metallic matter to a very marked extent. The viscosity of steel decreases rapidly with increasing temperature, thus permitting rise of inclusions through a less viscous medium. Increasing the slag temperature also increases its fluidity, aiding the absorption of non-metallics by the slag. This trend toward higher operating temperatures will necessarily involve the further development and application of basic or neutral refractories in furnace construction, and will especially demand radically improved roofs and ports. Future developments in recuperators and regenerative systems may prove quite helpful in improving the thermal efficiency of the openhearth furnace.

Rapid strides are being made toward accurately measuring liquid steel temperatures in the furnace while refining the heat. The most encouraging results are being obtained with an open end tube equipped with a radiation-sensitive device such as a photocell or a high speed radiation pyrometer; this assembly, when thrust beneath the slag, will provide a reliable indication of bath temperature in about 5 sec. Such a development will permit, for the first time, adequate study and control of the complex physical chemistry involved in steel refining.

As a further means of improving uniformity and achieving reproducibility of physical and mechanical properties in steel the openhearth metallurgist needs, and will certainly develop, a device which will quickly and accurately determine dissolved oxygen content of the metal, so that a truly "balanced" state of deoxidation may be achieved in the finished product. Further experience with the modified vacuum-fusion method proposed by Derge may indicate a direct solution of this problem. Similar quick and accurate methods for nitrogen and aluminum are desirable; doubtless other elements present in steel in almost infinitesimal quantities will be of profound future interest.

Notwithstanding thermal and metallurgical inefficiency the basic openhearth will probably continue to account for the major proportion of steel ingot tonnage in America for many years to come. When operations resume peace-time levels many stationary furnaces restricted to cold iron charges will probably be shut down. At the same time the large tilting furnace will enjoy increased popularity by virtue of its greater adaptability in the duplexing of hot metal, either from converters or into electrics.

Fast Working Electrics

Impelled by war, the electric furnace capacity of this country has been tripled in three short years. This perhaps over-stimulated expansion program will compel its owners to develop integrated duplexing or triplexing operations to accelerate production rates, and to bring power and electrode costs into line with fuel costs in the competing processes. The large basic electric arc furnace is an ideal refining medium. It is adaptable to a wide variety of raw materials, it is thermally and metallurgically efficient and capable of producing the finest of quality steels. With many large units in position to function as the end refiner in a combination blast furnace-openhearth-electric process, or cupola-converter-electric process, it is inevitable that an increasing proportion of the industry's tonnage will be finished in electric furnaces. C. D. King, chairman of the operating committees of U. S. Steel Corp., has stated that the use of liquid charges in large electrics bids fair to increase the productive capacity per unit to an extent which offers interesting competitive possibilities with conventional openhearth steels for certain types of products in the post-war era. It is improbable that further expansion in installed electric furnace capacity will occur for some time, except in a few isolated cases where hydroelectric power is cheap and natural fuel is expensive, or within large integrated companies in position to feed them with liquid metal.

When peace-time operations are at last resumed the steel industry must be prepared to embark upon a strenuous period of competition with light metals, non-ferrous metals and plastics. In all probability steels will then be truly tailor-made — produced not simply to a specified range of chemical composition, but to specifications embracing properties and performance tests of end products as well. In anticipation of such a situation, constantly increasing uses will be found for modernized instrumentation, automatic control systems, and broader metallurgical control of all iron and steel making operations.

REACTIONS BETWEEN HOT STEEL AND FURNACE ATMOSPHERES

By Floyd E. Ha
Furnace Engine
Buick Motor Divi
General Motors C
Flint, Mich.

THE COMPLETE STORY of gas reactions with metallurgical products involves thermodynamic considerations which few have the patience to follow. However, a simplified tabulation may be made which requires a minimum of explanation in its application to common furnace atmospheres. Thus it seems advisable to present the tabulation early in this paper and then attempt to explain its import and its adaptability to specific processes.

Five elements are chosen, namely, carbon, oxygen, hydrogen, nitrogen and iron. Eleven reactions, involving the formation of compounds from these elements, are to be charted. First, however, a brief explanation must be given concerning the elementary principles which govern the use of the data.

Thermochemical calculations deal primarily with energy concepts. Thus, in a formation reaction, the energy available to produce the reaction has a special significance, and is represented by ΔF°. This change in available energy (termed "free energy") is expressed in B.t.u. per pound per molecular weight (abbreviated as lb-mol) and represents the energy available for the reaction as written; specifically it is the free energy of the product minus the free energy of the reactants, the thermal output (or intake) of the reaction. If ΔF° is negative in value, then energy is available to form the compound; if positive, the compound may dissociate to the elements from wh it is formed.

This change in free energy varies with te perature, principally because the specific heats the substances involved are not the same, a may therefore be expressed as a linear functi of the absolute temperature. A simple expr sion will give quite correct data over a reasona range. For example, for the formation of carb dioxide, at any given temperature between 8 and 2200° F., we may write:

$$C+O_2=CO_2;\ \Delta F^\circ=-169{,}723-0.082T$$

where T is degrees above absolute zero, that T=°F+460. This means that, for the temper ture range given, CO_2 is a very stable compou with little tendency to dissociate to its elemen carbon and oxygen. To dissociate it into its el ments a great deal of heat would have to "pumped into" the compound.

In contrast the formation of methane expressed as:

$$C+2H_2=CH_4;\ \Delta F^\circ=-38{,}283+26.398T$$

For this reaction, we state that at low temper tures, CH_4 is stable; at elevated temperatures tends to break down to gaseous hydrogen a solid carbon. This is true, since at temperatur where ΔF° is positive, the compound possesses greater energy content available for chemic reaction than do the elements from which it

formed; hence the compound dissociates. Conversely when ΔF° is negative, the elements combine to form the compound.

Free energy equations, then, tend to show, in a qualitative manner, the *direction* in which reactions proceed at given temperatures. It can be shown by considering the so-called mass law and equating ΔF to zero that a direct relationship exists between ΔF° and a term designated "the equilibrium constant" ordinarily symbolized as K. This latter term will develop a quantitative relationship between the gases found in the reaction. We write:

$$\text{Log}_{10} K_p = \frac{\Delta F^\circ}{4.576T}$$

where K_p, the constant, is defined (for a simple gaseous system) as the product of the partial pressure of the reactants, divided by the partial pressure of the compound. By substituting the value of ΔF° in the equation for Log K, we write for the formation of methane:

$$C + 2H_2 = CH_4;\ \Delta F^\circ = -38{,}283 + 26.398T;$$

$$\text{Log } K_p = \frac{-8370}{T} + 5.770$$

The complete significance of this expression for the formation of methane will be developed in the following paragraphs:

The activity of the *solid*, carbon, is taken as unity; this means, simply, that the amount of carbon present is immaterial to the course of the reaction, providing only that *some* solid carbon is always present at a given equilibrium condition. The activity of a *gas*, however, when only one mol* is represented by the reaction, is directly proportional to its partial pressure, which in turn is represented by its volume per cent. But, from familiar considerations of the mass law, it is necessary to consider the number of mols of each gas represented. Thus for this methane reaction,

$$K = \frac{(\text{Volume fraction of } H_2)^2}{\text{Volume fraction of } CH_4}$$

*A "mole" or "mol" is a quantity by weight proportional to the molecular weight. For example a lb-mol of O_2 weighs 32 lb.; a g-mol of H_2 weighs 2 g.

Chart of Formation Reactions

Reaction	ΔF°	Log K_p	Product	No.
$C + O_2 = CO_2$	$-169{,}723 - 0.082T$	$\frac{-37{,}098}{T} - 0.018$	CO_2	1
$C + \frac{1}{2} O_2 = CO$	$-48{,}339 - 20.766T$	$\frac{-10{,}566}{T} - 4.539$	CO	2
$H_2 + \frac{1}{2} O_2 = H_2O$	$-106{,}346 + 13.135T$	$\frac{-23{,}245}{T} + 2.871$	H_2O	3
$C + 2H_2 = CH_4$	$-38{,}283 + 26.398T$	$\frac{-8370}{T} + 5.770$	CH_4	4
$3C + 4H_2 = C_3H_8$	$-47{,}327 + 70.61T$	$\frac{-10{,}344}{T} + 15.433$	C_3H_8	5
$\frac{1}{2} N_2 + 3/2 H_2 = NH_3$	$-23{,}273 + 27.811T$	$\frac{-5087}{T} + 6.079$	NH_3	6
$\frac{1}{2} H_2 + \frac{1}{2} N_2 + C = HCN$	$+55{,}184 - 7.736T$	$\frac{+12{,}062}{T} - 1.691$	HCN	7
$Fe + \frac{1}{2} O_2 = FeO$	$-113{,}149 + 15.194T$	$\frac{-24{,}732}{T} + 3.321$	FeO	8
$3Fe + 2O_2 = Fe_3O_4$	$-471{,}586 + 73.360T$	$\frac{-103{,}079}{T} + 16.035$	Fe_3O_4	9
$3Fe + C = Fe_3C$	$+7{,}412 - 2.745T$	$\frac{+1620}{T} - 0.60$	Fe_3C	10
$4Fe + \frac{1}{2} N_2 = Fe_4N$	$-8{,}070 + 14.388T$	$\frac{-1764}{T} + 3.145$	Fe_4N	11

CONDITIONS: 1. Temperature range is 800 to 2200° F., wherein the ΔF° values are accurate to ±500 B.t.u./lb-mol.

2. ΔF° represents free energy for the standard state (pressure = 1 atmosphere).

3. K_p with signs as given represents $\frac{\text{Reactants}}{\text{Product}}$ where reactants are on left of equality sign, products to right.

This manner of expression is rather awkward when dealing with unequal mols, and with diluted gas systems. Hence it is customary to let P equal the pressure of the system (in this case $H_2 + CH_4$) and to put $H_2 + CH_4$ equal to unity. Thus we write, solely for expression purposes:

Let $x = H_2$

$1 - x = CH_4$

Then $K = \frac{(Px)^2}{P(1-x)} = P\frac{x^2}{1-x}$

To further clarify this conventional mode of expression, an example will be given:

Let the temperature, °F be 1000° F.

Then $T = 1000 + 460 = 1460$

But $C + 2H_2 = CH_4$; $\text{Log } K_p = \frac{-8370}{T} + 5.77$

$$= \frac{-8370}{1460} + 5.77 = +0.038$$

Whence $K_p = 1.091$

Then $1.091 = P\frac{x^2}{1-x}$

When P = 1 atmosphere (the total pressure for $H_2 + CH_4$), P disappears from the equation:

$$1.091 = \frac{x^2}{1-x}$$

Solving this equation we get $x = 0.633$, which is the proportion of hydrogen in the mixture. Its analysis is, then, $H_2 = 63.30\%$

$CH_4 = 36.70\%$

Suppose, however, that the combined pressure of H_2 and CH_4 is only 0.5 atmosphere. We then proceed to solve as before, substituting 0.5 for P:

$$1.091 = 0.5\,\frac{x^2}{1-x}$$

whence x is found to be 0.7454. For equilibrium, then, $H_2 = 74.54$ parts and $CH_4 = 25.46$ parts. This last is a relative ratio; the actual percentages in this case are, of course, 0.5 times these amounts, since P=0.5, that is to say, $H_2 = 37.27\%$, $CH_4 = 12.73\%$, and an inert gas 50%.

These examples should illustrate the meaning of the symbol, K_p. The subscript is significant, as shown, when the number of mols for the gas system reactants differs from the number representing the product. (Another way of saying this is that pressure affects the equilibrium if the reaction involves a change in volume.) The chart or table is presented on page 85, and its application to practical problems will be developed with specific examples.

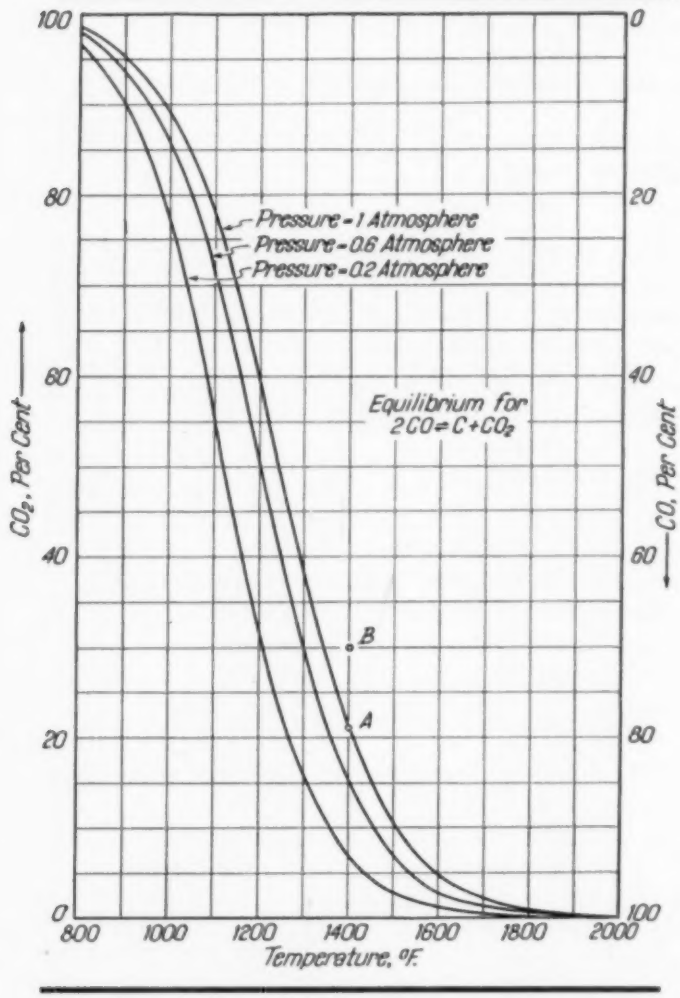


Fig. 1 — Proportions of CO and CO_2 in Equilibrium With Carbon at Temperatures Between 800 and 2000° F., and at Pressures of 0.2, 0.6 and 1.0 Atmosphere

From the table, reactions expressed by combinations of any of these elements and compounds may be readily investigated. To use this chart properly the meaning of the formation reaction must be recognized, and this can be easily shown.

It will be noted that the convention used in writing these formations places the elements on the left, and the product on the right of the equality sign; thus:

$$C + O_2 = CO_2;\ \text{Log } K_p = \frac{-37{,}098}{T} - 0.018$$

An equally correct expression is

$$CO_2 = C + O_2;\ \text{Log } K_p = \frac{+37{,}098}{T} + 0.018$$

The first equation defines the *formation* of CO_2 while the second gives the *dissociation* data merely by changing the sign of the Log K_p formula. Furthermore, since the products, as charted are hypothetically obtained in all cases directly from their specific elements, we may construct the proper expressions for ΔF° and Log K_p for any reaction if we put the correct significance on the sign and number of mols involved. This can be shown best by actual examples, of which four are given, with the solutions graphed.

Decomposition of Carbon Monoxide

The reversible reaction is written

$$2CO \rightleftarrows CO_2 + C$$

Here two mols of CO are represented on the left and one mol of CO_2 on the right; the element, C, a solid, may be neglected. We put into the 2CO enough energy to decompose it into its elements and take out the energy that is evolved when CO is formed from its elements. Mathematically we add twice the value of Log K_p in line No. 2 of the table on page 85, changing the signs to the corresponding value in line No. 1. Thus:

$$\text{Log } K_p = -2\left(\frac{-10{,}566}{T} - 4.539\right) + \left(\frac{-37{,}098}{T} - 0.018\right)$$

Simplifying, for the reaction

$$2CO = CO_2 + C;\ \text{Log } K_p = \frac{-15{,}966}{T} + 9.060$$

Suppose now we wish to know the partial pressures (relative amounts) of the two gaseous constituents when the system is in equilibrium at 1400° F. and 1 atmosphere pressure. In the above equation T is absolute temperature, therefore T = 1400 + 460° = 1860° and

$$\text{Log } K_p = \frac{-15{,}966}{1860} + 9.060 = 0.476$$

$$K_p = 2.992$$

If x is the proportion of CO and $1-x$ the proportion of CO_2, then $K_p = P\frac{x^2}{1-x}$

Substituting $2.992 = 1\frac{x^2}{1-x}$

(pressure P on the system being 1 atmosphere)

Solving, $x = 0.791$

Which means that at 1400° F. and at 1 atmosphere pressure, the reaction is in equilibrium when 79.1% of the gas is CO and 20.9% is CO_2. This is marked as Point *A* in Fig. 1, containing graphs computed in this manner for three different pressures.

If a mixture of CO and CO_2 in contact with hot carbon at 1400° F. were to be analyzed and it contained say 70% CO (Point *B*, in Fig. 1) we would immediately conclude that the system (that is, the proportions of the two gases) was not in equilibrium with the hot carbon, and that the chemical reaction

$$2\,CO \rightleftarrows C + CO_2$$

would be proceeding from right to left, the excess CO_2 taking up some of the surplus carbon to form more CO. Opposite conditions hold for gas proportions located below the equilibrium curve for a given pressure.

The "Water Gas" Reaction

The so-called water gas reaction is between carbon monoxide and steam, and produces carbon dioxide and hydrogen. (Really this, as well as the other ones here, are "reversible" to the extent that they proceed only in part; the relative proportions of the gaseous ingredients when equilibrium is reached depends on the temperature.)

$$CO + H_2O = CO_2 + H_2$$

We take out from the chart

$$\text{Log } K_p = -\left(\frac{-10{,}566}{T} - 4.539\right)$$

for decomposing CO

$$-\left(\frac{-23{,}245}{T} + 2.871\right)$$

for decomposing H_2O

$$+\left(\frac{-37{,}098}{T} - 0.018\right)$$

for formation of CO_2

Adding these items we have, for the water gas reaction

$$CO + H_2O = CO_2 + H_2;\ \text{Log } K_p = \frac{-3287}{T} + 1.65$$

Suppose we work this out for 1600° F. T = 1600 + 460 = 2060° absolute. Then

$$\text{Log } K_p = \frac{-3287}{2060} + 1.65 = 0.054$$

$K_p = 1.13$ for 1600° F. (Point *C* on Fig. 2)

Figure 2 has been worked out on this basis; the equilibrium is independent of pressure since there is no volume change.

Iron Oxide From CO_2 or H_2O

The reactions for the formation of FeO and Fe_3O_4 from iron and CO_2 are written as follows, and the value of Log K is derived from the tabular quantities in the same manner as already expounded.

(a) $Fe + CO_2 = FeO + CO$; $\text{Log } K = \frac{1800}{T} - 1.2$

(b) $3FeO + CO_2 = Fe_3O_4 + CO$;

$$\text{Log } K = \frac{-2351}{T} + 1.551$$

The reactions between hot iron and steam are as follows:

(c) $Fe + H_2O = FeO + H_2$;

$$\text{Log } K = \frac{-1487}{T} + 0.450$$

(d) $3FeO + H_2O = Fe_3O_4 + H_2$;

$$\text{Log } K = \frac{-5638}{T} + 3.201$$

Note that for these reactions the symbol K_p is replaced by K, without the subscript. When an equal number of mols is indicated for the gaseous phase on both sides of the equation, the pressure of the gas system has no effect on the reaction. Thus whether these oxides are formed or reduced depends upon the ratios, CO_2/CO or H_2O/H_2, only, and these reactions are independent of the total pressure of the gas system, insofar as the equilibrium mixture of the gases is concerned.

Computations as shown for the water gas equation have been made for all four of these reactions forming iron oxides and the results are in the curves of Fig. 3. Note that each curve is

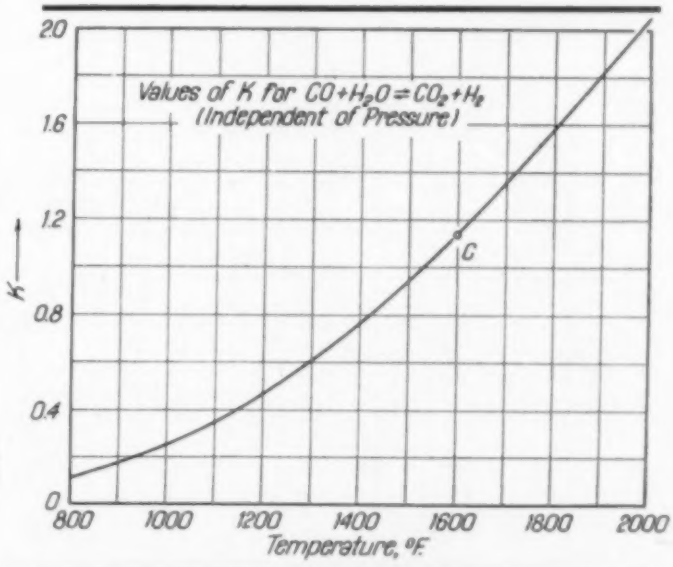
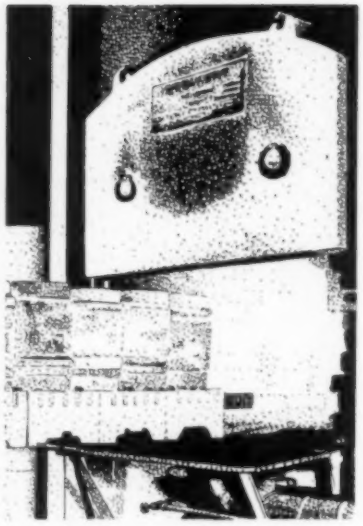


Fig. 2 — Variation of K With Temperature for the "Water Gas Reaction"

$$CO + H_2O \rightleftarrows CO_2 + H_2$$



labeled on both sides. Take, for example, the curve for oxidation of iron by steam. Above the line is written the equation

$$Fe+H_2O \rightarrow FeO+H_2$$

which means that if an atmosphere whose temperature and composition limits are above the line is in contact with the hot iron the iron will be oxidized. Similarly, below the line is written

$$Fe+H_2O \leftarrow FeO+H_2$$

which means that any conditions plotted below the line will tend to reduce any iron oxide that may exist.

Specifically, an atmosphere consisting of 75% H_2 and 25% H_2O will reduce any iron oxide that may be present either as FeO or Fe_3O_4 at 1400° F. (point *E*), but will scale metal at 900° F. (point *F*). Conditions that may be safe at high temperature may therefore damage the work as it cools.

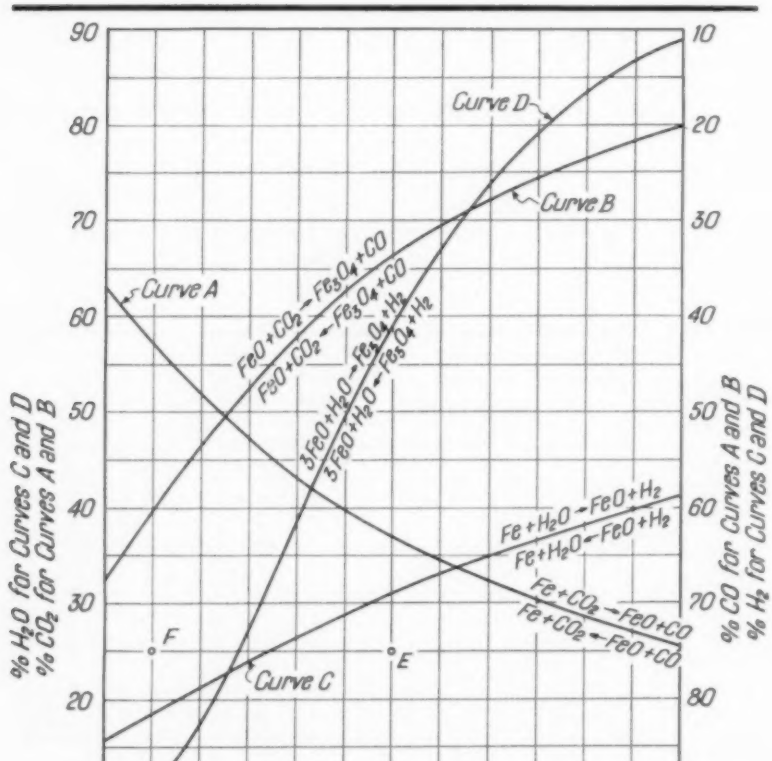


Fig. 3 — Gas Proportions for the Oxidation of Iron or Reduction of Iron Oxide by $CO:CO_2$ Mixtures (Curves A and B) or by $H_2:H_2O$ Mixtures (Curves C and D), or for Equilibrium in Either System

Carbon Availability

In this final illustrat we will attempt to prov specific data for the comm cial problem of supplying bon to a steel surface by me of the atmosphere surround it. Thus, while in previ reports in *Metal Progress* carburizing* the term "add carbon" has been used in c nection with carbon added steel specimens, here t term "available carbon" w express the maximum amount of carbon pounds that may be obtained from a given composition at a given temperature. For t purpose a carrier gas commonly used in co mercial carburizing, 20% CO, 80% N_2, will compared on a volume basis to natural gas wh chief constituent is CH_4. For ease comparison, CO and CH_4 will be tak as representing the reactants of the two gases. For each a partial pressu of 0.2 atmosphere will be chosen, whi approximates closely the common co mercial usage.

We write, for the generator ga

$$Fe+2CO=Fe\cdot C+CO_2$$

Here the expression Fe·C is used denote the saturated austenite as repr sented by the steel surface during t carburizing process. The activity the carbon we take as unity. (No that the formation of Fe_3C is not post lated. For this condition an entire different activity must be used, shown in line No. 10 in the chart.) F this condition and for a temperature 1700° F. the computation proceeds follows:

$Fe+2CO=Fe\cdot C+CO_2$;

$$\text{Log } K_p=\frac{-15,966}{T}+9.0$$

$$T=1700°+460°=2160°$$

*"'Case Depth'—an Attempt at Practical Definition" (Aug. 1943, p. 265 "Maximum Carbon in Carburized Case (April 1944, p. 683). "Carburizing a Diffusion Data for Eight Common C burizing Steels" (May 1944, p. 910-B "An Analysis of a Typical Carburizi Gradient" (June 1944, p. 1111). "A Form lation of the Carburizing Process" (Se 1944, p. 488).

Substituting for T in formula:

$$\text{Log } K_p = \frac{-15{,}966}{2160} + 9.060 = 1.668;$$

whence $K_p = 46.56$

Let the volume of the active gas equal unity; that is,

$CO + CO_2 = 1$; $x = CO$; $1 - x = CO_2$

But $K = P\frac{x^2}{1-x}$, and P is chosen as 0.2 atmosphere.

Hence $\frac{x^2}{1-x} = \frac{46.56}{0.2} = 232.8$,

and $x = 0.9957$, $1 - x = 0.0043$

Thus, of the total carbon in 0.2 lb-mol, which is 0.2×12 or 2.4 lb., only 0.43% is *available* for carburization from the reaction at 1700° F.; the rest is locked up in gaseous compounds in a system in equilibrium. Since at 60° F., 1 lb-mol represents 380 cu.ft. of gas, the pounds of available carbon in 1 cu.ft. of 20% CO gas is, for the carburizing reaction at 1700° F.,

$$\frac{2.4 \times 0.43}{100 \times 380} = 0.0000272 \text{ lb.}$$

This is plotted as Point *G* in Fig. 4; similar computations for other temperatures enable the line marked "Curve for Charcoal Gas" to be mapped.

A similar computation may be made for natural gas, writing for an assumed gas composition from line No. 4 in the chart, $Fe + CH_4 = Fe \cdot C + 2H_2$;

$$\text{Log } K_p = \frac{8370}{T} - 5.770$$

Solving as before for P = 0.2 atmosphere we find, for 1 cu.ft. of natural gas at 60° F., 0.0337 lb. of carbon is available for carburizing at 1700° F. This is plotted as Point *H* on the "Curve for Natural Gas" in Fig. 4, and is approximately 1200 times the amount for an equivalent volume of generator gas, as shown at Point *R* in Fig. 4.

Conclusion

These data were assembled and compiled from spectroscopic determinations, heats of combustion and formation, and from various experimental deductions. References covering each source are too numerous for mention, although many will be found in the appendix of Lewis and Von-Elbe's "Combustion Flames and Explosion of Gases". Incidentally, Chapter XVI of this book outlines the thermodynamic functions of gases in an extremely concise and rigid manner, but it is far from elementary.

Thermodynamics alone does not tell the complete story, since little is said of reaction *rates*. For example, the true equilibrium of ammonia, nitrogen, hydrogen and iron indicates practically a complete dissociation at 950° F., yet it is a simple matter to maintain a dissociation of below 30% in the nitriding process at this temperature, merely by employing a fair rate of ammonia flow. It is true, however, that if the data say a reaction may *not* take place, then the reaction will *not* proceed. Thus, complete control of atmosphere reactions indicates the individual analysis of actual operating factors.

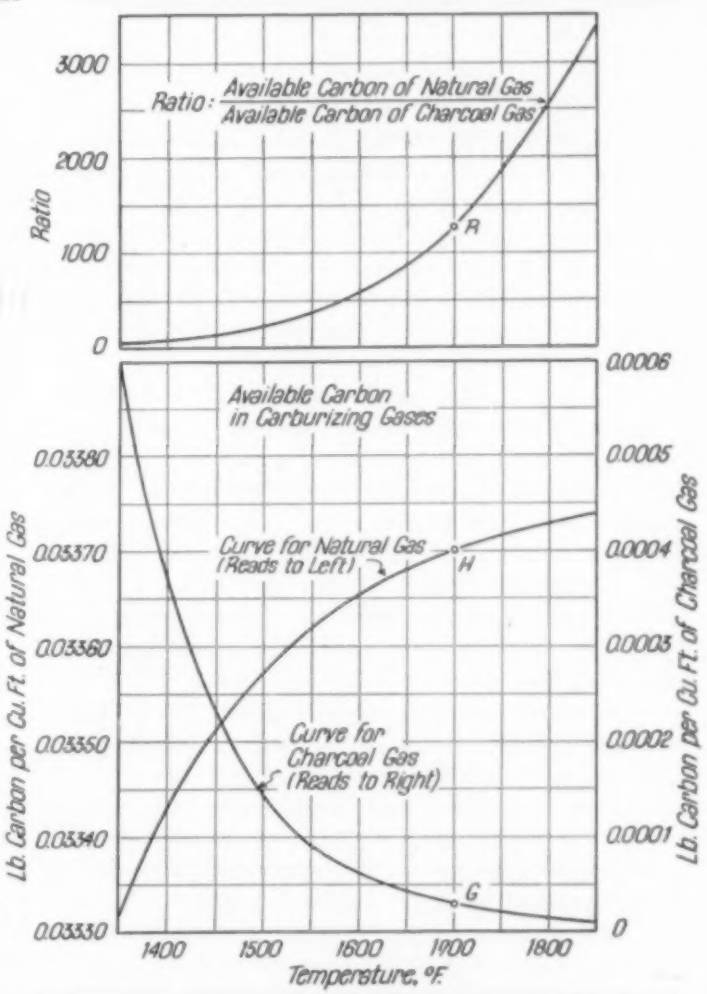


Fig. 4 — Available Carbon for Carburizing Steel in 1 Cu.Ft. of Charcoal and 1 Cu.Ft. of Natural Gas at Various Temperatures; Also Ratio of the Two. (Note large difference in scale at right and left)

PROGRESS IN THE MECHANISMS OF PRODUCTION

By Lester V. Colwell
Assistant Professor
Department of Metal Processing
University of Michigan

ONE OF THE MOST frequently asked questions in recent months concerns the influence of war-time technical developments on peace-time manufacturing. Time alone can answer many phases of this question. However, the post-war planning and discussions of industry, labor, and government reveal certain trends which are less conflicting than might be expected in a world steeped in revolution.

Industry is facing the fact that technical progress can only go forward, not back. In many lines applicable to commercial production, war-time advances in production techniques and speeds have amounted to what ordinarily would have taken a generation of normal competitive life. Some industries cannot go back to less efficient methods of production. Other industries cannot overlook the possibilities of adapting ordnance methods to their own operations.

Organized labor is clamoring for steady and high income, in the face of an impending supply the greatest in our history. Only the most advanced techniques can keep them busy and produce a tremendous amount of quality products at low prices — a prime essential for constant employment of 60 million workers.

Government is interested if for no other reason than taxes. How else can it support itself, except by taxation of solvent citizens?

Thus it appears without further argument that industry, labor, and government are vitally interested not only in promoting extensive use of war-time technical developments but also in developing still better methods. What then, are the new and significant developments which can be used to further large scale civilian production? Readers of *Metal Progress* are familiar with many of them but it will be well to summarize, and then describe in more detail, those which have been applied more extensively during the past year or two.

Most of the newer developments can be grouped into one or more of three main categories — materials, pre-fabrication methods, and fabrication or machining.

Materials

Basic metals now in use are essentially unchanged, since we haven't discovered any new elements to add to the periodic table. Perhaps the most significant development in metals is the tremendous expansion of capacity for the production of aluminum and magnesium. The greater efficiency of large units has already substantially reduced the costs of these materials and we may expect a further improvement in their competitive position relative to ferrous alloys. This trend will be accentuated when improvements in forging, sand casting, die casting, and high speed machining can be employed more extensively. Even at the present day, some potential applications in war production are being delayed to avoid interrupting production schedules. A sub-

stantial expansion can be expected in the use of stainless steel as a result of better fabricating methods and its favorable reception by consumers.

Carbide Tools — The widespread adoption of sintered carbide cutting tools has focused attention on certain difficulties which must be overcome before they can be completely satisfactory on some jobs. Some of these problems will be solved by metal producers after the war when properties of the material to be cut can be sacrificed, if necessary, to reduce machining costs.

Powder Metallurgy and sintered metals are for the most part a new development in pre-fabricating and production techniques. However, a whole new field has been opened up where new properties of metals are of interest. For example, controlled density and porosity have been added to the usual selection of properties. Variable thermal and electrical conductivity will probably be added in the near future, as well as controlled machining characteristics.

Synthetics — Outside the field of metals lies the broad field of synthetics, including not only plastics but also glass, wood, paints, lacquers, ceramics, and artificial textile fibers. These have overlapped so that few persons comprehend the full significance of the war-time developments. Not being one of the few I will not attempt to evaluate their competitive position.

Some of the materials have been covered with military secrecy and it is probable that the rumored properties have been exaggerated. However, synthetics will certainly offer a wealth of properties and processes with which designers can exercise their imagination on new and old products for quite some time.

Plastics must first overcome a black-eye, an unfortunate consequence of war-time shortages. Some of the more plentiful were substituted for metals in unfavorable duty, and this has stigmatized plastics as *ersatz*. This is unfortunate since it was never intended that plastics could completely replace the metals for which they were substituted. This condition can be overcome by resourceful and intelligent future applications.

Pre-Fabrication of Materials

There have been no recent radical departures in pre-fabrication methods. This does not mean that substantial progress has not been made. The developments have been gradual and, for the most part, came from efforts to extend the scope of processes already in fairly general use. Those processes include sand casting, permanent mold casting, die casting, drop forging, press forging, hammer forging, cold heading, upsetting, extrusion, rolling, drawing and centrifugal casting. Relative newcomers are sintering of powdered metals and casting by the precision investment or "lost wax" process.

Sand Casting — The principal developments in sand casting hinge upon a more general use of steel and semi-steel castings. This has brought about a refinement of techniques in sand control and melting control and has greatly increased the use of non-destructive testing equipment, particularly X-rays.

An interesting scheme with good chance of extensive use is the one by which oil lines, prefabricated from steel tubing, are placed in molds like cores and then cast integral with the crankshaft, housing or other part being made. This method can probably be used in the manufacture of hydraulic control equipment for machine tools, gas and fluid passages in internal combustion engines, compressors, and other similar equipment. The advantages are low cost, more efficient fluid flow, and fewer troublesome, deep-hole drilling jobs. The idea of sheet metal steel cores bonded permanently to castings is not new, but its possibilities for producing better castings at lower cost will justify its more extensive use. Much new research work is also being done on molding and core sands and binders.

Centrifugal Casting — Fairly widespread interest is shown in centrifugal casting. This process is notable for at least three things, *(a)* its ability to produce remarkably clean castings with little effort; *(b)* a high yield in weight of castings per unit weight of melt since sprues, runners and risers frequently can be eliminated; *(c)* lower cost and less time spent in preparing the mold, since the parabolic coring peculiar to this process can be used instead of sand cores where the shape of the casting is favorable. The variety of castings is somewhat limited by the nature of the process. In addition, lack of the special equipment — even though fairly simple — is holding back its adoption except where very large quantities of castings are required.

Forging and Die Casting have gradually progressed, due generally to improvements in the forging or casting properties of alloys, better control apparatus, larger capacity equipment, and (in casting) to increasing pressures. The reconversion period will bring a considerable increase in the number and size of such parts made of aluminum and magnesium alloys. This trend, combined with newly developed equipment for precision machining at exceptionally high cutting speeds, will make aluminum and magnesium serious contenders for many products previously fabricated from iron and steel.

Powder Metal Products are being used quite extensively even now, despite the fact that the manufacturing processes are in the earliest stages of development. The greatest volume of production, other than the well established field of sintered carbide tools, has been with iron base and copper base compositions. The possibilities for new and more useful compositions are almost unlimited. For example, there have been as yet no recorded attempts to combine metal powders and metallic compounds with ceramics; however, it is feasible that entirely new materials will be developed by bonding metallic with non-metallic compounds. Such attempts might give us new cutting tool materials with properties approaching those of diamond. Similarly, materials which could be varied over wide ranges of electrical resistance, thermal conductivity, density, and porosity would open up new fields for design.

The present procedure for fabricating powder metals consists of, first, green bonding at room temperature with the pre-forming machines commonly used for plastics; second, sintering in controlled atmosphere furnaces; and finally, coining or cold pressing where closer tolerances are required. Attempts are being made to obtain greater density by means of supersonics and by sintering in the die. Improvements in electrical induction heating equipment and die materials have reached a stage where commercial applications of the latter method may soon be expected.

Precision Casting — All of the processes discussed so far are well adapted to large lot sizes and some — such as sand casting — are also practicable for small lots. Significant strides have been made in the use of plaster mold casting and the somewhat similar "lost wax" process, both well adapted to small lots. They fabricate intricate shapes without much expensive machining, in lot sizes where the cost of special cutting tools, jigs, and fixtures cannot be justified. Both processes should be quite useful in commercial aviation and other industries where new models must be well built even though in small quantities.

Fastening of Components

Space does not permit a detailed discussion of the various methods and devices for fastening component parts together. However, it seems appropriate at least to mention welding, brazing, and soldering.

One of the most interesting developments in welding is the **smothered- arc** process. Controlled feeding rate, along with the granular flux used for smothering the arc, produces joints sufficiently smooth and regular that machined components, so joined, seldom need be re-machine before assembly. One example can be found i the manufacture of electric motor housings.

The increased availability of equipment f high frequency electric induction heating is givin renewed importance to **brazing and solderin** Copper brazing of sheet metal components wa quite common before the war when controlle atmosphere, tunnel type furnaces were used fo large quantity production. The very rapid an localized heating possible with induction equip ment will extend this process down to includ much smaller lot sizes. Where service require ments permit it, screw machine products may b broken down into simpler components an assembled by either brazing or soldering, thu saving time, material, and costly tooling.

Machine Tools and Operations

High Speed Milling — If not the most impor tant, at least some of the most spectacular war time developments in manufacturing have bee in machining and machine tools. In the pre-wa period, grinding at speeds of 5000 to 6000 ft. pe min. was considered the practical limit to cuttin speeds. Already we are milling aluminum alloy at more than four times practical grindin speeds! "But what of the effect on the cuttin edges?" may be asked. The author recalls hav ing seen an accident wherein a small automobil travelling at a speed well over 50, sheared a lo of rivet heads off a rivetted bridge girder. Thi was done by the frame made of low carbon stee plate with remarkably little damage to the sof metal part which functioned as a cutting tool

Some of the examples of high speed machin ing given wide publicity are admittedly mor spectacular than useful. Machining time ha been reduced to seconds on some jobs in shar contrast to minutes required by primitive fixture used on the same jobs. Regardless of some mis applications, interest has been aroused and th stage is set for casting aside traditional practice as rapidly as the new techniques are perfected The Office of Production Research and Develop ment is currently sponsoring projects at the Cali fornia Institute of Technology and the University of Michigan for determining those condition which will enable industry to do as much high speed milling of ferrous alloys as present equip ment will permit without design changes.

It is gratifying that there is generally greate latitude in the selection of tool shapes, cuttin speeds, feeds, and depths of cut for high spee milling than for conventional milling. Some have chosen to refer to high speed milling as "negativ

rake milling". It is incidental that the references for rake angles were selected in such a manner that the usual angles are in the neighborhood of zero. Another set of references could have been selected such that the useful angles would be either all negative or all positive. Changes in performance resulting from new tool angles are gradual and the cutting tool is usually unaware of the fact that the rake angle has passed from positive to negative or vice versa.

Consideration of high speed machining should be divided into two distinct classes; one for ferrous alloys and one for non-ferrous alloys. The latter will be cut at speeds several times faster than the former. To date the most successful operations on steel have been roughing cuts on forgings, wherein production rates have sometimes been increased several fold.

Machine Tool Designs for post-war use show trends toward *(a)* a separate line of machine tools for exploiting the very high cutting speeds possible with non-ferrous metals; *(b)* more machines of the single purpose type; *(c)* more fully automatic, multiple cycle machines equipped for wide range and easily changed cycles, and *(d)* more machines equipped with either attached or integral automatic sizing devices which will reject off-limit pieces.

Aluminum, magnesium, red brass, yellow brass, copper-silicon alloys, and even phosphor bronze can be milled at cutting speeds above 10,000 ft. per min. with carbide tools. Machines are being designed specially for such high speed operation. They must be equipped with powerful motors, since it requires a definite amount of energy to cut a cubic inch of metal, regardless of speed. These machines will cut to very accurate dimensions, and produce surfaces at least as smooth as are obtained by good commercial grinding. Production rates will be comparable with disk grinding, so that even die castings can be milled economically when desired.

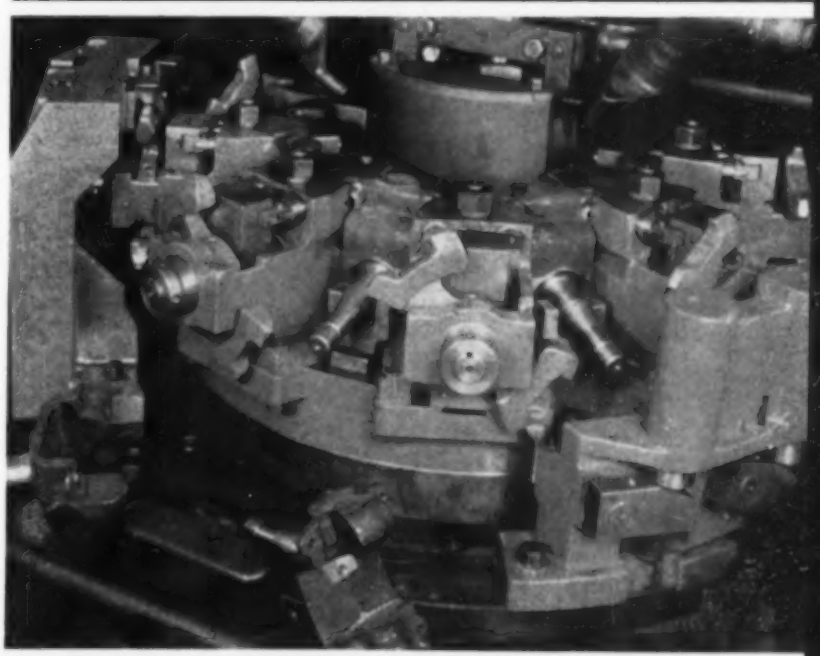
It is possible to drill holes in non-ferrous alloys with accuracy approaching that of precision boring and at very high production rates. Extremely high spindle speeds and feeds are required, beyond the capacity of present machines.

The new machine tools for high speed machining of ferrous alloys will be much more rigid and powerful, so that carbide cutters can be used to the greatest advantage. Fewer speed selections will be needed, therefore gear trains can be reduced to a minimum. The use of single reduction worm gears, with the gear mounted as near as possible to the nose of the spindle, has been quite successful.

Form Copying Machines — Manufacturing expedients have dictated much of the final design of components in the automotive industry. This cannot be permitted in aircraft engines where parts are stressed almost to the limit to save weight. Consequently, when it became necessary to produce these engines on a large scale there was a tremendous increase in the demand for automatic form copying machines. This in turn stimulated the development of mechanical, hydraulic, and electrical control apparatus. The new devices exert little or no force on the master. Some of them "hunt" position, since they are self-energizing, but the range of hunting has been reduced and it is possible to hold dimensions to within 0.001 in.

Controls — Much progress has also been made in adapting electronic controls to feeding mechanisms. The equipment is simple, compact, and easily adjusted over a wide range for cycle changes. Hydraulic controls have been steadily improved and expansion of facilities has reduced costs. Hydraulic energy is still one of the most adaptable, compact, and powerful means of power transmission in machine tools.

These and other developments in materials, tools, and processes give labor, industry, and government another pioneering job which will be done in the American tradition of progress and a better standard of living for all.



$6500 Automatic Clamping Fixture for Milling Four Surfaces on Steering Knuckles (100 per Hr.)

BITS AND PIECES

"Bits and Pieces" has been known as "Metallurgicus' Own Department", thereby meaning that it is an open forum for ASMembers to present brief notes about shop practices. (The reward is an ASM book.) However, the leading article has frequently been signed "Metallurgicus", the pen name of a valued contributor. It should not be necessary, but apparently it is, to say that he and the Editor are two different persons.

Who Knows About Temper Colors on Stainless Steels?

THE SPECTRUM of the so-called "temper colors" on ordinary carbon or low alloy steels, from light straw to gray, has an honored place in the history of the heat treating art. "Drawing the temper" to a dark straw, avoiding the blue color range, were formerly necessities of instruction; with the adoption of pyrometric control, the use of temper colors as guides to heat treatment became less essential, but frequent use may be made of these interference colors in tracing heat patterns, as for example, around welds. The Bethlehem Steel Co. publishes in several of its booklets very accurate reproductions of these common temper colors.

Stainless steels would be expected to show considerably different color vs. temperature relations due to their resistance to oxidation. Desiring some information on this matter, I looked in vain through the logical sources; "The Book of Stainless Steels" has a brief and indefinite comment that the temper colors on cutlery grades appear at higher temperatures than on ordinary steels — and that was all I found.

A sketchy series of tests was run on the 16% Cr, 13% Ni, 3% Mo alloy (A.I.S.I. Type 316) and indicated that straw persists to about 900°, then the colors appear with blue at 1000 to 1025°, and gray at 1150° F. At 400° F. a fugitive purple was noted. These colors on a polished surface resulted from one hour at heat in an open flame tool furnace.

Surely this subject has been explored. This sterile note is by way of a plea for information; send in your data to "Bits and Pieces", and be rewarded not only by the satisfaction of having thrown light into a dark corner, but also (if your contribution is published) by any book (except the Handbook) published by ASM.

METALLURGICUS

"Blue Printing" on Metal

NUMEROUS accounts have been published of methods developed by airframe manufacturers for photographing line drawings on prepared metal surfaces, thus quickly making intricate "layouts" on them ready for the sheet metal worker. It is not so well known that simple methods are available for direct printing of full scale inked drawings from tracing paper or linen. While most applications will probably be on flat sheet metal, the process works also on bent, uneven or oxidized surfaces.

The metal need only be reasonably clean of loose dirt and grease, and is lightly sprayed with a rapid drying Kodak Layout Paint. Spraying can be done in ordinary room light; if prepared surfaces are not used fairly soon they should be stored in the dark. Printing is done exactly like a blue print is made, under arc or mercury vapor light. Washing is first with warm, weak ammonia water. A vigorous spray of tap water then washes off the exposed coat, leaving only white lines on the metal where black lines appeared on the drawing. The job is completed by protecting the white markings by a thin spray of transparent "Layout Paint Primer".

The markings tightly adhere and withstand bending and ordinary shop handling. They are not only always as accurate as the original drawing, but any instructions lettered thereon are automatically transferred to the metal. (H. J. CHRISTY, Eastman Kodak Co.)

Memory Aid for Welders

IN THE DECEMBER 1942 issue of *Metal Progress* Joseph Kielb suggests the connection between the negative sign for current (a *straight* line) connected with the *straight* electrode which gives "*straight*" polarity. May I suggest the following:

Since the positive side of electric arc is hotter (*positive* heat) than the negative side and since the work usually requires more heat than the weld rod due to its greater mass, the work is usually made the positive side of the arc (which results in a straight connection or "straight" polarity). The opposite is, of course, the reverse polarity. (E. JAMES SAX, U. S. Patent Office)

Hardness Tester With Automatic Certification Stamp

IT IS COMMON PRACTICE in aircraft plants to check the hardness and heat treatment of small parts and sub-assemblies made of aluminum alloy sheet. For this purpose the portable testing devices described briefly in "Critical Points" (July 1943 issue, page 85) are convenient. With such an indentation hardness tester, equipped with a dial, an inspector could take as many as 20 readings a minute, but this speed would be delayed by the necessity of stamping with hammer and die each part with his personal OK mark.

To combine the testing and stamping operations into an automatic cycle, I have devised a fixture for a standard tester as shown in the accompanying photograph. A heavy base or flat anvil carries a mast at one edge on which slides a bracket carrying testing mechanism at front and electric motor at rear. This bracket is adjustable vertically for various thicknesses to be tested, so the indenter moves against the surface at the proper angle. The depth of indentation is measured by a finger on the dial, and electrical contacts on this gage are set for the specified limits. Above the tester, and at one side, is another arm carrying a vertical solenoid which actuates the stamp.

The machine is set for the thickness of the material and the minimum satisfactory hardness — 80 in the case of ST aluminum sheet. Parts are then fed under the indenter point of the hardness tester unit which moves up and down at the rate of 43 times per min., a rate found most satisfactory in practice. If the part measures up to the specified hardness, the electrically operated plunger automatically stamps it with both the inspector's and the hardness stamps. If it is too soft, the plunger remains inactive, and the part cannot possibly be certified. The entire operation is automatic, and could, in fact, be performed by a blind operator. Both the visual reading of the hardness tester dial and the hand stamping of parts are completely eliminated.

Motor Driven Hardness Tester for Sheet Metal Parts, Equipped With Limit Gage and Stamping Device for Certifying Hardness

It is estimated that 3,000,000 parts have passed through the original machine during the first year of operation, at a saving of at least 1050 man-hours — nearly half a year for one inspector. (ADOLPH VLCEK, JR., Inspector, Army Division, Glenn L. Martin Co.)

Drilling Pyrometer Holes Through Furnace Linings

FACED with the necessity of drilling several 1⅜-in. holes through a 5-in. firebrick sidewall, we attempted to improve upon the use of a rock bit and 80-mesh Carborundum slurry, a scheme that required over 2 hr. per hole.

We took a 10-in. length of 1-in. extra strong steel pipe, and fitted a standard No. 4 Morse taper shank into one end. At the opposite end four slots ¼ in. wide by ¼ in. deep were milled on two diameters at 90°. Four recesses ⅛ in. deep by ¼ in. wide were then milled adjacent to the previous slots. Deposits of a hard-facing rod

consisting of 10-mesh tungsten carbide particles in a mild steel jacket ("Stoody Tube Borium") were arc welded into each recess only, the ¼-in. slot being left for chip space. Since great accuracy was not required the welded deposits were not dressed.

This tool was mounted in a radial drill and adjusted to 125 rpm., giving a peripheral speed of 45 ft. per min. The holes were located through the steel furnace jacket and drilled by hand feed of a rate of approximately 1 in. per min. The elapsed time per hole, 5 in. deep, was from 6 to 7 min., including the backing out of the drill for removal of the drillings, thus being a great improvement over the 2 hr. anticipated for rock bit. All drilling was done dry.

Some further tests indicated that red building brick can be drilled with this set-up at the rate of 3 in. per min., kaolin brick at 1 in. per min., and "korundal" brick (90% Al_2O_3) at 1 in. in 5 min.

Little expense or time is involved in preparing the drill. Slot sizes or spacing may be varied but should be evenly spaced to avoid excessive side thrust. (K. J. TRIGGER, Asst. Prof. of Mechanical Engineering, University of Illinois)

Comprehensive Exposure Chart for Micrography

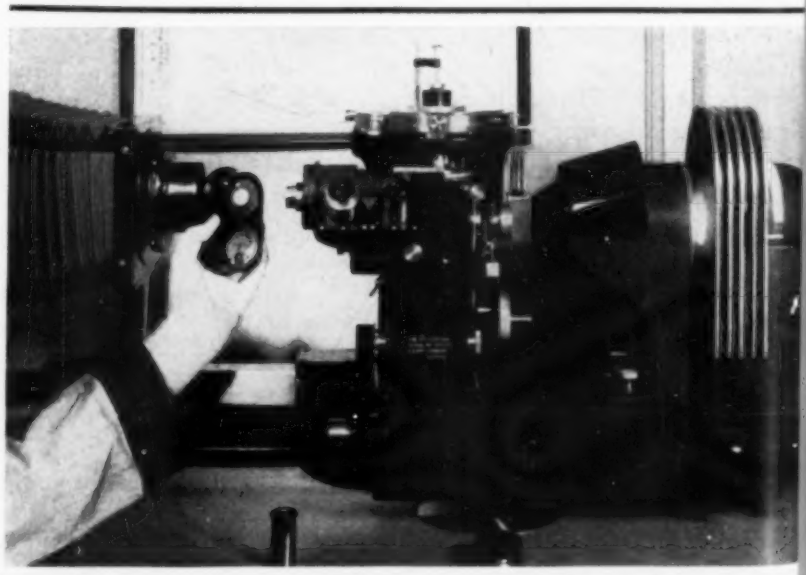
IN "BITS AND PIECES" in the May 1943 issue of *Metal Progress* a timer for micrography was described by J. L. Waisman. We have made use of that information, modified the procedure and have made a chart covering the entire range of standard magnifications. [It is reproduced as a data sheet, page 96-B.] As far as we know, this information can be used only on the Bausch & Lomb Research Model Metallograph, when using the carbon arc for illumination, and Wratten & Wainwright metallographic plates for negative material, developed in DK-50 for 5 min. However, similar charts can of course be made for other instruments.

A Weston Sight Meter, Model 703, reading up to 75 foot-candles is the type of photometer used. The front bellows support is first pushed back until the 10-cm. division is visible, all filters are removed, the field diaphragm is closed to a reading of 1½, and t camera eye-piece is removed. The method holding the meter to obtain the exposure is sho in the photograph at the bottom of this page; t meter should touch the front bellows support, shown, and be tilted at a slight angle to facilit observations.

A variation in light intensity will be notic as the carbons burn off and feed in. Therefo it is advisable to take the meter reading imme ately after the carbons have advanced and cent the arc at the same time. The photograph shou be taken during a similar moment after havi made certain that the yellow and green filters a inserted, and the field stop increased to give t desired area to be photographed. The feeding- of the carbons can be produced at will by relea ing the clutch mechanism, increasing the a length until the motor drive begins to opera and re-engaging the clutch.

The reading for foot-candles obtained fro the meter is converted into exposure time by co sulting the chart, selecting the desired magnific tion, and reading the exposure time on t abscissa scale. This value, if short, cannot b used directly on the camera but must be co verted into suitable shutter speeds which a found in the upper right hand corner of the char If more than one shutter setting is necessary t make the total time, the plate is merely given multiple exposure.

It will save much time if as many as twel plates are exposed, and developed simultaneous using a plate rack. (ANTON L. SCHAEFFLER, Chi Metallographer, A. O. Smith Corp.)



Light Meter Used to Determine Exposure Time for Micrograp

Lengthen Service Life

...regardless of unit size!

4 TIMES LONGER LIFE

Eight years' service instead of two, was obtained by a large chemical company through specifying Nickel cast iron for this 8-ton ring. Plain iron used here corroded and eroded ½" per year. This Nickel alloyed iron wears less than ⅛" in the same time.

Increases Result/Dollar Ratio...

In products and applications . . . from a wrench to a railroad . . . records show that a little Nickel goes a long way to lengthen product life, to reduce bulk and deadweight, and to save maintenance costs.

When compared with costs involved, metals to which Nickel is added invariably rise sharply in service value . . . due to improved performance.

Nickel imparts strength, hardness, toughness, resistance to corrosion, heat and abrasive wear. In all fields of industry Nickel offers significant advantages. Send us details of your problem for our recommendations.

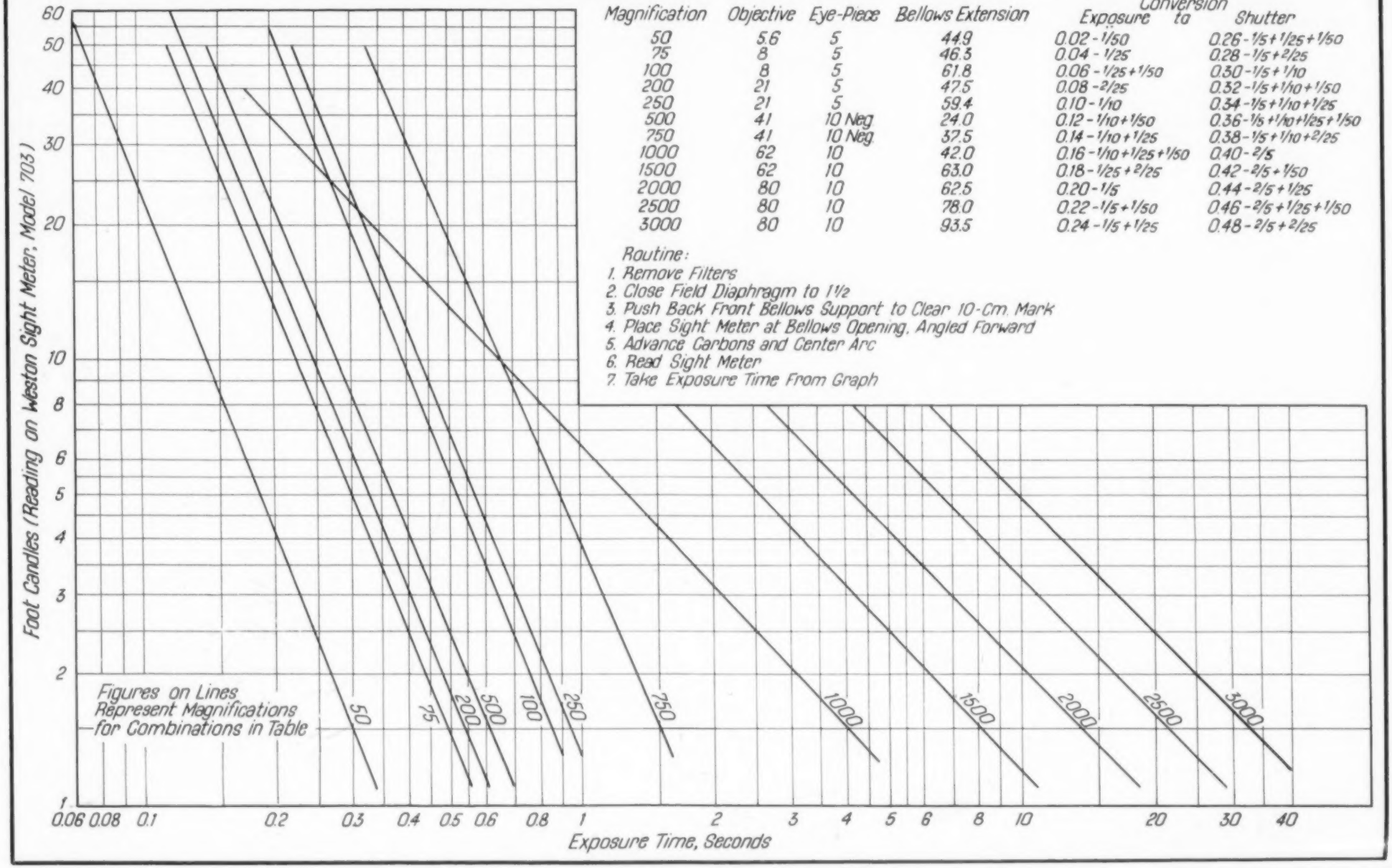
THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

☆ CONSERVE WITH NICKEL ☆

Exposure Chart for Bausch & Lomb Research Metallograph

Using carbon arc, yellow and green filters, Wratten & Wainwright plates, developed 5 min. in DK-50

By Anton L. Schaeffler



Magnification	Objective	Eye-Piece	Bellows Extension	Conversion Exposure	to Shutter
50	5.6	5	44.9	0.02 - 1/50	0.26 - 1/5 + 1/25 + 1/50
75	8	5	46.3	0.04 - 1/25	0.28 - 1/5 + 2/25
100	8	5	61.8	0.06 - 1/25 + 1/50	0.30 - 1/5 + 1/10
200	21	5	47.5	0.08 - 2/25	0.32 - 1/5 + 1/10 + 1/50
250	21	5	59.4	0.10 - 1/10	0.34 - 1/5 + 1/10 + 1/25
500	41	10 Neg.	24.0	0.12 - 1/10 + 1/50	0.36 - 1/5 + 1/10 + 1/25 + 1/50
750	41	10 Neg.	37.5	0.14 - 1/10 + 1/25	0.38 - 1/5 + 1/10 + 2/25
1000	62	10	42.0	0.16 - 1/10 + 1/25 + 1/50	0.40 - 2/5
1500	62	10	63.0	0.18 - 1/25 + 2/25	0.42 - 2/5 + 1/50
2000	80	10	62.5	0.20 - 1/5	0.44 - 2/5 + 1/25
2500	80	10	78.0	0.22 - 1/5 + 1/50	0.46 - 2/5 + 1/25 + 1/50
3000	80	10	93.5	0.24 - 1/5 + 1/25	0.48 - 2/5 + 2/25

Routine:

1. Remove Filters
2. Close Field Diaphragm to 1½
3. Push Back Front Bellows Support to Clear 10-Cm. Mark
4. Place Sight Meter at Bellows Opening, Angled Forward
5. Advance Carbons and Center Arc
6. Read Sight Meter
7. Take Exposure Time From Graph

Metal Progress Data Sheet, January 1945

PROPERTIES AND CHARACTERISTICS OF MAGNESIUM FORGINGS

By J. Colin Smith
Development Engineer
American Magnesium Corp.
Cleveland

MAGNESIUM and its alloys, like other metals, have their individual characteristics that should be understood in order that one may take full advantage of the material in designing new parts or redesigning old ones. Many magnesium commodities, such as sand castings, die castings and, more recently, permanent mold castings, are well known and are widely used today in aircraft engines, engine accessories, and airframe parts. With the present supply of magnesium more than sufficient to take care of visible requirements, and with fabricating capacities greatly expanded, it is now practical for the designing engineer to consider this metal seriously, especially in the forms most suitable.

It is not so widely known that magnesium *forgings* are readily obtainable today, and offer interesting mechanical properties. Several alloys are available, covered by governmental and commercial specifications as shown in Table I.

Table I — Specifications for Magnesium Forging Alloys

Alloy	Army-Navy Aeronautical	A.S.T.M.		S.A.E.	A.M.S.*
		Number	Grade		
AM65S	AN-M-22	B91-41T	16	53	
AM-C57S	AN-M-20	B91-41T	8x	531	4350
AM-C58S	AN-M-21 Grade F	B91-41T	9x	532	4360
AM-C58S-T5	AN-M-21 Grade FA				

*Aeronautical Material Specifications (issued by the Society of Automotive Engineers).

Choice of Alloy — Selection from a group of alloys for an application depends upon the conditions that the forging is required to meet. Some of the requirements may be in the performance of the part in service, but there are also cases where certain properties are necessary to fabricate successfully and economically the forging for the final assembly. Tensile yield strength is normally one of the more important design values, but there are many cases where some sacrifice in tensile yield strength for a higher elongation value is desirable. Secondary operations after machining, such as bending, forming, or welding may influence the alloy choice.

Machinability of a forging alloy is often an important requisite when the amount of machining is considerable, especially where the relative cost of the finished part to the rough forging is high. In the case of some metals, one alloy is often chosen because of its superior machinability over other alloys of the same metal. All of the magnesium alloys machine equally well and have exceptional machining characteristics. Therefore, when the cost of *machining* a forging is one of the important factors, and the mechanical properties of any of the magnesium forging alloys are sufficient from a design viewpoint, the easiest alloy to forge should be selected.

Table II — Mechanical Properties of Magnesium Forging Alloys (A.S.T.M. Test Specimens)

Alloy	Tensile Minimum Values Parallel to Grain Flow			Typical Values						
	Ultimate Strength	Yield Strength (a)	Elongation in 2 In.	Ultimate Tensile Strength	Tensile Yield (a)	Elongation in 2 In.	Shear Strength (b)	Endurance Limit (c)	Brinell Hardness	Charpy Impact
AM65S	36,000 psi.	22,000 psi.	7%	40,000 psi.	28,000 psi.	12%	16,000 psi.	10,500 psi.	52	2.0 ft-lb
AM-C57S	38,000	22,000	6	42,000	26,000	8	21,000	16,000	55	2.2
AM-C58S	42,000	24,000	5	45,000	30,000	6	22,000	17,000	60	1.8
AM-C58S-T5	42,000	28,000	2	48,000	34,000	6	22,000	16,000	72	

(a) Yield strength is the stress at which the material exhibits a permanent set at 0.2%.

(b) Shear strengths are single-shear values obtained from double-shear tests.

(c) Endurance limits are based on 500 million cycles of completely reversed stress. The R. R. Moore type of machine and specimen was used in determining these values.

Specified minimum and typical properties of the forging alloys are shown in Table II, above.

With the exception of AM-C58S, none of the forging alloys shown in this table respond to heat treatment. AM-C58S can be aged, and in this condition is designated as AM-C58S-T5. The aging of this alloy primarily increases the tensile yield strength at the expense of elongation. Compressive yield strength is also increased.

The original minimum values of AM65S were 35,000-psi. tensile, 20,000-psi. yield, and 6% elongation. Recently, it has been found possible to increase these minima to 36,000-psi. tensile, 22,000-psi. yield, and 7% elongation. An increase in typical properties to the values shown in Table II was also made at the same time.

Cost — There are many times when the designer would like to know the relative cost of the different alloys. Design features of any forging influence the cost, and certain things (such as unsymmetrical displacement of metal, location, and size of flanges and bosses) can often be done with one alloy that would incur higher tooling and forging costs in another alloy. Generally, the relative costs of the different alloys being discussed are, in the order of increasing costs: AM65S, AM-C57S, AM-C58S, AM-C58S-T5.

Such a cost comparison should only be used as a guide, subject to confirmation by actual estimates. Close cooperation between designer and forging manufacturer regarding the alloy choice and the design of the part will certainly help in selecting the most satisfactory alloy, as well as the most economical.

AM65S is the most versatile and adaptable of the magnesium forging alloys. Extensive studies of its forgeability have been made, and it has been found that for most parts, from simple to complex in nature, it can be forged as readily as the aluminum alloy 14S. AM65S can be fabricated on diversified equipment, such as hammers, upsetters, rolls, mechanical presses, and hydraulic presses. This is not only interesting but important, as it enables the manufacturer to utilize whatever equipment and fabricating methods are most suitable to produce a satisfactory forging.

In considering magnesium as a constructional material, an inspection of the typical and minimum properties of the forging alloys shown in Table II indicates good design values. Combined with good forging characteristics, these properties should influence a wider acceptance of magnesium forgings, not only in present fields — which consist largely of aircraft applications — but also for industrial applications where light weight and a high strength-weight ratio are desirable.

Applications and Examples — Present uses of magnesium forgings include control fittings for

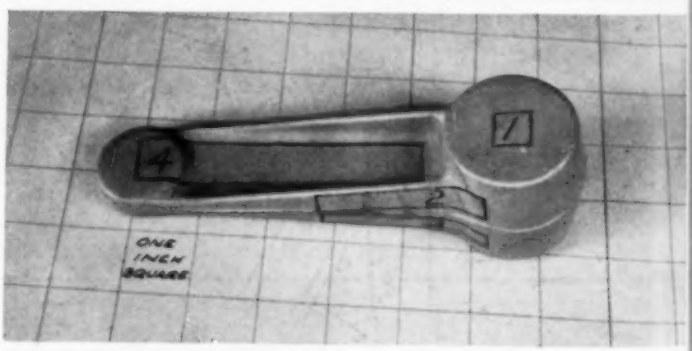


Fig. 1 — Press Forging; Alloy AM65S; Weight 0.70 Lb.

Bar	Tensile	Yield	Elongation
No. 1	32,100 psi.	17,700 psi.	8.3%
2	40,630	28,080	14.0
3	40,200	26,980	15.3
4	40,500	28,480	11.1

aircraft where not only weight saving is desirable, but where high rigidity and stiffness are necessary. Examples of parts shown in Fig. 1 to 4 inclusive are typical forgings common to many aircraft control systems. Many parts of this nature are actually stronger than design loads call for, because of the fabricating limitations on minimum thickness of the webs and ribs; in other words, the dimension is the same as if made in a heavier alloy. In such cases, it is possible to take advantage of the full weight saving characteristics of magnesium.

There are many other places where magnesium can be used advantageously, not primarily to save weight, but to gain greater rigidity by employing a greater mass of material with no weight penalty.

Captions list the mechanical properties of bars cut from actual forgings. Locations of the test bars are indicated, and values are averages from two or more forgings.

Figure 1 shows an aircraft control fitting of average size, a press forging weighing 0.70 lb. made from AM65S alloy. The lower properties of bar No. 1 are characteristic of tests taken normal to the parting plane of the forging.

Figure 2 shows the properties obtained on a lighter part made as a hammer forging. The average properties of test bars cut from various locations are well above the minimum values for AM65S, including the bars from location No. 3, which are considered transverse bars.

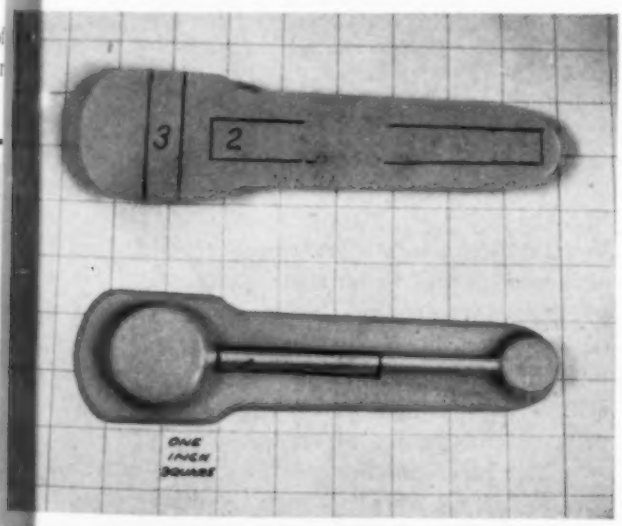


Fig. 2 — Hammer Forging of Alloy AM65S; Weight 0.37 Lb.

Bar	Tensile	Yield	Elongation
No. 1	38,410 psi.	27,480 psi.	10.7%
2	38,780	27,680	8.8
3	38,280	27,390	7.2

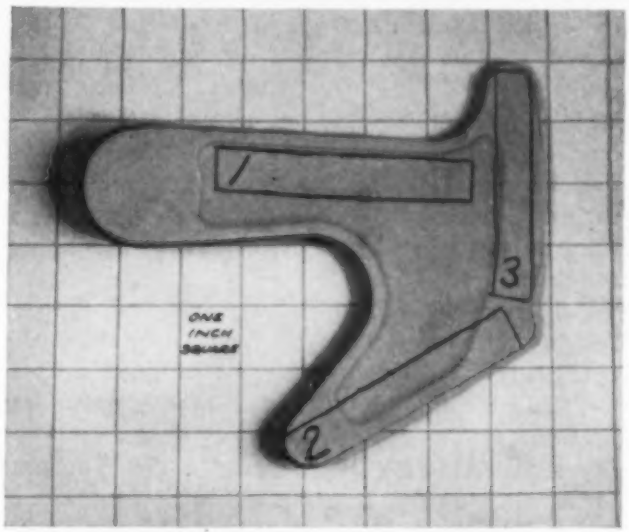


Fig. 3 — Press Forging Requiring Considerable Stock Displacement; Weight 0.55 Lb.

Bar	Tensile	Yield	Elongation
	Made of AM65S		
No. 1	38,300 psi.	22,100 psi.	11.5%
2	39,100	25,980	13.7
3	37,980	22,100	15.3
	Made of AM-C57S		
No. 1	42,950 psi.	24,750 psi.	14.6%
2	39,000	24,400	6.6
3	42,900	20,550	19.3

The forging shown in Fig. 3 is an example of one that requires a considerable amount of stock displacement by spreading at one end and a heavy boss at the opposite end. Properties of alloys AM65S and AM-C57S are shown for the same part. It is interesting to note that the tensile yield strength of either alloy is essentially the same for this particular forging.

Pressure Fittings — Forged hydraulic valve bodies and cylinders are excellent applications for magnesium where full advantage of its weight-saving possibilities can be taken. The economy of such parts should also be a prime consideration. Many such parts must withstand high pressures and consequently must be leakproof, and the characteristics of a forged structure are desirable. For such applications, the final product, machined from a forging, is often cheaper than when produced by other methods, since the machining losses and rejections are lower in number.

Figure 4, showing such a part made in three different alloys, is a good example of this type of forging. It also illustrates a type of part where the rough forging cost is low compared to the total cost of the finished machined piece.

Transverse Loadings — Most forgings are

designed in such a way that maximum loading in service takes advantage of directional properties which usually are in a direction parallel to grain flow. There are, however, many parts which have transverse or partially transverse bosses or sections that are heavily loaded, and which must, therefore, have good transverse properties. Forging technique and equipment then play an important part in producing a satisfactory product.

Figure 5 is a good example of this type of forging. The test bars cut from location No. 3 constitute an excellent example of good properties in a section that is apparently a transverse section.

Alloy AM-C58S — The most difficult magnesium alloy to forge is AM-C58S, which sometimes limits it to intricate parts, usually where drastic cross sectional changes are involved. Certain types of forgings can be produced, but often the tooling expense is greater for this alloy than for some of the other alloys. This is due to the need for additional blocking dies and subsequent operations. Parts that are symmetrical or involve no extensive spreading are readily produced.

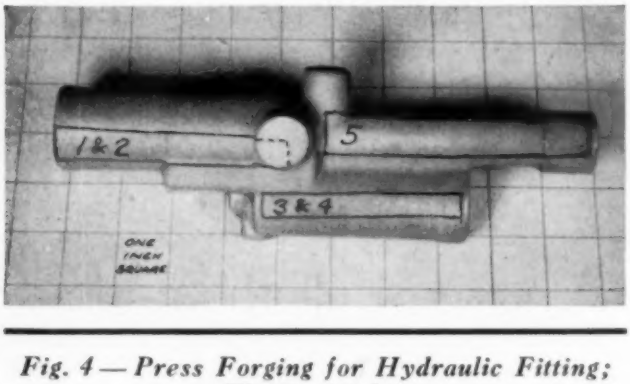


Fig. 4 — Press Forging for Hydraulic Fitting; Weight 1.4 Lb.

Bar	Tensile	Yield	Elongation
	Made of AM65S		
No. 1	39,800 psi.	28,500 psi.	9.9%
2	41,500	31,500	10.5
3	41,400	31,250	10.5
4	40,000	27,500	9.9
5	40,400	28,000	9.9
	Made of AM-C57S		
No. 1	44,000 psi.	27,750 psi.	12.7%
2	43,500	29,500	11.5
3	44,500	30,250	12.7
4	45,400	32,500	11.3
5	44,000	30,000	9.9
	Made of AM-C58S		
No. 1	40,000 psi.	32,500 psi.	5.6%
2	45,000	29,500	9.9
3	45,500	30,750	10.5
4	46,600	31,500	9.9
5	45,400	32,500	9.9

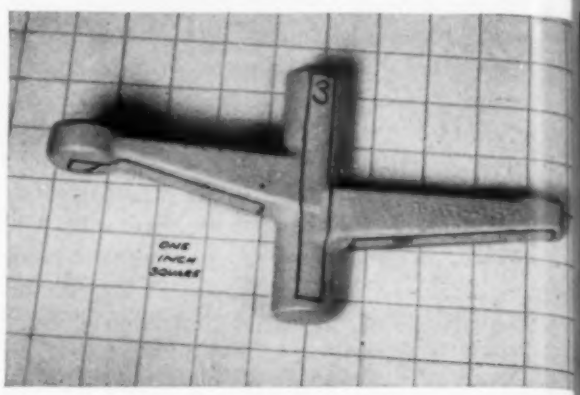


Fig. 5 — 0.85-Lb. Hammer Forging of Alloy AM65S to Carry Loads in Transverse Direction

Bar	Tensile	Yield	Elongation
No. 1	38,100 psi.	24,580 psi.	12.0%
2	38,000	24,800	12.4
3	38,000	27,400	10.3

AM-C58S provides higher properties than the other alloys, especially in the aged condition designated as AM-C58S-T5. Figure 6 illustrates a type of part that can be readily made in this alloy. It is a relatively large press forging, weighing 19.3 lb.

Other Uses — In addition to the foregoing illustrations of different applications, magnesium forgings have been used for gear trains, impellers, bearing caps, levers, tube fittings, tank fittings, brackets, and cover plates. Experimental forgings have been made for heavy parts such as nose pieces, crankcases, and propellers.

Forgings Versus Castings

Magnesium forgings are replacing castings of both magnesium and aluminum because of their higher yield strength and elongation values. With most casting alloys, higher yield strength is obtained at the expense of elongation. A comparison of typical mechanical properties of some of the magnesium forging alloys and cast magnesium and aluminum alloys is shown in Table III. Yield strength and elongation values for these different alloys are of especial interest.

The increase in mechanical properties of the forging alloys over the casting alloys is evident. When availability and cost are important, AM65S is the best choice of the forging alloys, especially when considering a forging in place of a casting. There is a natural tendency on the part of many designers to select the highest strength alloy available when another alloy with better forging characteristics but slightly lower

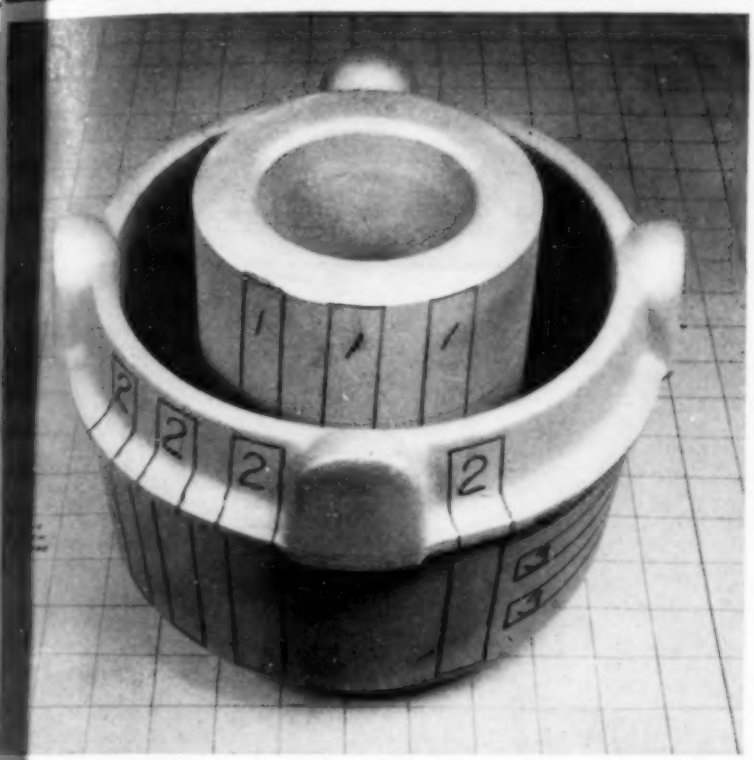


Fig. 6 — Large Press Forging of Alloy AM-C58S; 19.3 Lb.

Bar	Tensile	Yield	Elongation
No. 1	43,800 psi.	22,400 psi.	12.0%
2	44,100	29,700	10.9
3	39,900	15,600	12.0

properties may often be just as satisfactory for the application.

Forgings are not ordinarily used for experimental or low production quantities, because of the die and tooling costs in comparison with the costs of castings when made in small quantities. Frequently, however, the properties of a wrought or forged material are essential for small or even experimental quantities, whereupon hand forgings are commonly used, eliminating die or pattern expenses, although additional machining time is necessary.

Design

In considering the design of any part, as it may be influenced by the choice of a forging or of a casting, certain facts will aid in selecting the best method. Because of the higher mechanical properties of a forging, thinner sections, within the limits of forgeability, can be used. Forgings usually require larger fillets and corner radii than castings, but in parts made of magnesium this is not undesirable, as either forgings or castings should be designed so as to eliminate sharp corners or abrupt changes in sections that might result in stress concentration. Bosses that can be cored in castings must be forged solid or, if large enough, with a web that may be punched out. Bushings or inserts must be assembled as a secondary operation after machining.

The higher mechanical properties and greater uniformity of properties of a forging allow the designer to use a lower safety factor than for a casting, and this often provides a greater saving in weight than a direct comparison of mechanical properties alone would presumably justify.

Design detail varies a great deal, depending on the shape, size, and alloy involved, as well as the type of forging equipment that can be used to make the part, but there are some basic principles that should be understood in order to be consistent with forge shop practices.

Minimum dimensional requirements for average size forgings are listed on page 102 for general guidance. These requirements are similar to those for aluminum forgings, about which a considerably increased knowledge has been attained during the past five years as a result of their extensive use in aircraft applications. Often die equipment built for aluminum forgings can be used for magnesium production, either without change, or with only minor changes in the die equipment. The size and design of any forging necessarily affects tolerances, and they may differ from this list, depending upon the design and

Table III — Typical Properties of Some Magnesium Forging Alloys and Magnesium and Aluminum Casting Alloys

Material	Alloy	Ultimate Tensile Strength	Tensile Yield Strength	Elongation in 2 In.	Compressive Yield Strength
Forged					
Magnesium	AM65S	40,000 psi.	28,000 psi.	12.0%	21,000 psi.
Magnesium	AM-C58S-T5	48,000	34,000	6.0	26,000
Cast					
Magnesium	AM260-T4	39,000	14,000	10.0	14,000
Aluminum	195-T4	31,000	16,000	8.5	16,000
Magnesium	AM260-T6	38,000	20,000	3.0	20,000
Aluminum	195-T6	36,000	22,000	5.0	25,000

complexity of the forging under question. Where a range is shown in the list, the lower limit applies to small forgings and the higher limit to average sizes.

Minimum Dimensional Requirements for:	Hammer Forgings	Mechanical Forgings Press
Sectional thickness	1/8 to 3/16 in.	1/8 to 3/16 in.
Machine finish allowance	1/16 to 1/8 in.	1/16 to 1/8 in.
Size tolerance	± 1/32 in.	± 1/64 to 1/32 in.
Flatness tolerance	1/32 in.	1/32 in.
Trimming tolerance	1/16 in.	1/16 in.
Draft per side	7°	3°
Draft, in. per in. per side	0.125	0.059

Generous corner and fillet radii are required for magnesium forgings; for small parts corner radii should be at least 1/8 in. and fillet radii at least 3/16 in. Ample radii do not add appreciable weight to the part, but materially help metal flow and die life.

Rib height should not exceed four times the rib thickness. Ribs with a full radius prolong the die life and also reduce initial die costs.

The question comes up of how large can magnesium forgings be made commercially, at the present time. Unless a drawing of the part in question is available, it is very difficult to answer an inquiry of this nature. Maximum size of a forging that can be produced, expressed either in area or weight, depends upon design and alloy, as well as size and capacity of equipment available in the forging manufacturers' plant. A 35,000-lb. hammer will handle dies big enough to produce a forging approximately 30 in. by 30 in. A 2500-ton mechanical press will take dies that will produce a forging about 14 in. by 14 in. Expressed in weight, about 100 lb. is the maximum for a hammer forging, and about 25 lb. for a press forging. This does not mean that a forging of maximum area and maximum weight can necessarily be produced.

Although most of the magnesium forgings that are being produced today are for the aircraft industry, the experience that is being gained by both the forging manufacturer and the consumer of the forgings will be helpful to the manufacturer of machinery and equipment for commercial applications. The future applications of magnesium forgings should be very extensive. Reciprocating parts of both light and heavy duty machinery, portable equipment of all kinds, parts for packaging, wrapping, and folding machinery, office equipment, machine tools, textile machinery — all offer applications for magnesium.

Many manufacturers will redesign their present product to take advantage of the improvements in materials that have been made in recent years, and it is certain that magnesium forgings will play an important part in this period.

1944 WAR-TIM

METAL FINISHE

METAL FINISHES have b radically changed in nature since the war start because of the scarcity of certain materials, a because of the desire to obtain dull finishes products to be used in the combat zone. It w be useful to list the more important changes, a to describe some of the recent electroplating ba in some detail.

Plastics — Current technical and popu scientific magazines have said much about t extensive use of plastics in our war produc Plastics do not rust and therefore do not nee protective coat. Plastic bases are also used paints to protect metals from corrosion. Aga metals can be inserted in plastic and there protected. The word "plastic" includes a ve long list of synthetic organic chemicals; amo them the following are finding extensive use war products:

1. Cellulose nitrate and acetate.
2. Shellac.
3. Bakelite.
4. Casein.
5. Soy bean products.
6. "Zein".
7. Urea formaldehyde.
8. Melamine.
9. Cast phenolic resins.
10. Vinyl resins.
11. Vinylidine chloride resins.
12. Styrene resins.
13. Acrylic plastics.
14. Ethyl cellulose.
15. Cellulose butyrate.
16. Regenerated cellulose.
17. Alkyd resins.
18. Coumarone indene resins.
19. Lignin.

By Harry P. Coats
Chemist
Firestone Steel Products
Akron, Ohio

Aircraft builders are familar with acrylic resin, used as transparent sheeting in the nose, gun turret and other positions of the plane; also with the use of valves and pipes made from plastic. Pilots' seats are made from plywood and plastics. It is probably not stretching the use of words to say that the laminated wooden surfaces for wings and fuselages, used widely in English fighters and bombers, are plastic products, depending on synthetics for glue-like adhesives and for impregnation.

Paint has had to replace scarce metal coatings. Vinyl resins are used to coat cans and electric wires to save tin. Zinc chromate primer, used on many war products, is well known for its passivating and rust inhibiting qualities. The only protection against carbon dioxide corrosion on the inside of steel cylinders is a phosphate coat, sealed with chromic acid.

Our brilliant colored paints have given way to olive drab and dirt colored paints.

Many steel parts are treated in a phosphate bath, then painted or oiled. Some steel parts are given an oxide coat and oiled. Phosphate coat has superior corrosion resistance to oxide coat. Protection of aluminum and magnesium is also important. A time saver for aluminum is the "alrock" process, wherein the clean, chemically oxidized surface is impregnated with sodium dichromate.

Clad Metals — Stainless clad steel for chemical equipment saves nickel and chromium. Copper clad steel for bullet jackets saves copper. Bronze coated steel for marine propellers saves copper and tin.

Plated Metals

Custom Plating — Cadmium and nickel were our best electroplates before the war for corrosion resistance but they have become too scarce to use now except where nothing else will answer.

Zinc, both hot dipped and electroplated, remains our best protection against corrosion, except in the humid tropics on movable parts, and in some marine exposures. Here we must employ cadmium because we have learned that basic zinc carbonate (white corrosion product) forms so rapidly in the humid tropics that moving metal parts, if zinc coated, will seize and fail to move. Cadmium plate is used for sea water exposure. Lately zinc plate passivated with chromium salts has been used to protect steel parts and to prolong the time before white corrosion products form.

Lead plate either hot dipped (as described by Messrs. Hack, Kondrat and Zahn in *Metal Progress* last October) or electrodeposited, has proven very useful to resist gasoline corrosion and to relieve the demand for zinc — lead being relatively plentiful in supply.

Chromium plate is used now to resist wear and corrosion, not to improve appearance. It is also used to build up under-cut machine parts. Porous chromium plating is used on engine cylinders to retain oil films and resist wear.

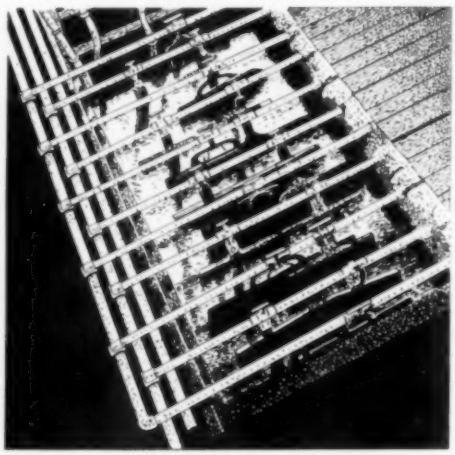
Brass plating was studied in detail prior to the war and widely used for all sorts of metal surfaces to which rubber should be bonded. Its use for this purpose is still extensive, although its former use for decoration or color-matching is seldom necessary in war-time. Captured German ordnance shows that our enemies have brass plated much matériel with the idea of protecting it from corrosion; however their plates are so porous that such steel parts rust fairly quickly.

Silver Plating has come in in a big way in the production of main bearings for airplane engines. The silver is plated 0.030 to 0.050 in. thick, machined to size, lead plated 0.001 in. thick, and finally given an indium flash 0.00004 in. thick, then heated to 310° F. for 2 min. The silver baths contain 6 to 16 oz. per gal. of silver cyanide plus potassium cyanide, and operate at 30 to 100 amp. per sq.ft. at about 130° F. One bath for plating plane bearings operates at 108 to 113° F. at 100

amp. per sq.ft. and has the following composition:

AgCN	40 to 43 g. per l.
KCN	38 to 42
K_2CO_3	45 to 80
KOH	8 to 14

Early in the war, quartermaster supplies (knives, forks and spoons) were stamped from S.A.E. 1010 steel and silver plated direct on the steel, but were not very satisfactory and were therefore discontinued. Copper is successfully silver plated for electrical contacts.



Strip Plating — Prof. Colin G. Fink says, "Electroplating has moved out of the automobile plants into the steel plants." That is, the trend is to plate the strip and fabricate from this, rather than to form from bare strip and plate the article. Steel strip coated with aluminum, lead-tin alloy, tin, zinc, or copper is thus available for fabrication. Certainly this is the greatest contribution recently made to metal finish.

Tin Plate — About 20% of the tin coated steel now being made is electroplated in order to save our vanishing supply of tin. By the method of electrodeposition 0.5 lb. per base box of tin can be applied. (The lowest weight of hot dipped tin is about 1.25 lb. per base box. A base box is 218 sq.ft.; a weight of 0.5 lb. of tin per base box is therefore 0.00003 in. thick.) Electrodeposits are melted, chemically treated, and lacquered. Even then cans made from this weight of tin are not corrosion resistant enough to pack certain corrosive foods. There is also a tendency to return to hot dip tin for heavier coats, especially for export. Weight of 0.75 lb. tin per base box is better, but not good enough for all cans. The War Production Board has set the upper limits in weight of tin for each food container, but long before this limit was officially set the steel manufacturers had installed electro-tin lines for the purpose of saving tin. Strip is plated at a speed of 300 to 1000 ft. per min. Plating time is therefore measured in seconds.

There are two chief types of plating baths — acid or alkaline. Sodium stannate is the chief alkaline plating bath, but a new potassium stannate bath is now in use. Since potassium stannate is more soluble than sodium stannate and the solubility increases with temperature, a higher current density can be employed and a shorter plating time is required. Acid baths deposit tin from stannous salts, so they require only half the amperes that the alkaline bath does, and c plate at a correspondingly higher rate. Besi this, the acid bath will tolerate a higher curr density. (On the other hand, the alkaline b has a greater throwing power than the acid bat Some acid baths are sulphate, some are chlori and another is chloride plus fluoride.

One acid bath, containing phenolsulpho acid plus an organic addition agent, is opera at 140° F. and 300 amp. p sq.ft. The strip is plated a rate of 285 ft. per min. T tin coat is melted or flow by electrical resistance. Th bath deposits 0.5 lb. of t per base box.

One chloride-fluori bath operates at 1000 ft. p min. with a current dens of 355 amp. per sq.ft. at 1 F., at a pH of 2.7, a catho efficiency of 97%, and anodic efficiency of 100 depositing 0.75 lb. of tin p base box. This bath contai 2 to 5 oz. per gal. of tin a ¼ oz. per gal. of organic addition agent. A to of 120,000 amperes is used in this installati The tin plate is melted by electric induction. is then given a chemical treatment to impro adhesion of subsequent enamels.

One sodium stannate bath operates at amp. per sq.ft., 180° F., and produces 0.5 lb. p base box of tin plate. The bath contains 16 per gal. of sodium stannate and 2 oz. per gal. caustic soda. The tin is melted by induction order to close pores and improve the brightne

Zinc Plating Strip Steel — Most strip is zi plated from the acid bath, some from the cyani bath. One installation uses both — first t cyanide then the acid.

Our war-time penny was a steel strip plat from a zinc cyanide bath, blanked and stamp Of course there is no zinc coat on the edge, b none is needed, because the adjacent zinc p tects the bare steel.

Copper Plated Steel Strip — Steel strip w electroplated with copper for bullet jackets fr a copper cyanide, potassium hydroxide bath 180° F. The deposit is 0.0002 in. thick on o side and 0.001 in. on the other side. There very little of this type of copper plating bei done now. Copper clad steel — made by castin thin layer of molten copper on one or both sid of a steel slab inserted in the mold, the compos slab then being hot rolled to thin plate or sheet has long been an article of commerce.

CRITICAL POINTS

By the Editor

GRATIFIED by the opportunity to visit the Naval Ordnance Laboratory at Washington Navy Yard, and to transmit some impression of the enormously important achievements of some 800 physicists, chemists, mathematicians and technologists assembled there in record time. *How* they have rendered so many enemy devices harmless, and at the same time vastly enhanced the lethal character of our own, is "classified" (Navy word for secret) — doubly secret because of the Editor's ignorance of magnetics and electronics. All there was to start with was a group of about 20 men directed by R. C. DUNCAN in a laboratory established in World War I to study pyrotechnics, mines, and exploders, when early in 1940 the Nazi use of magnetic mines required immediate countermeasures. The British quickly devised the scheme of de-gaussing a ship with a girdle of electrical conductors around the hull. The American problem was to refine this device so it would be properly effective in all parts of the world (terrestrial magnetism varies from place to place), without waste of precious copper cable, applied very promptly (even built into a ship with other parts of the design), and its efficiency tested within a few hours or even minutes. The emergency uncovered another instance where pure research of the purest kind came to instant help. E. A. JOHNSON, an expert on terrestrial magnetism with the Carnegie Geophysical Laboratory, and RALPH D. BENNETT, an authority on electrical measurements with the faculty of Massachusetts Institute of Technology, came to the Navy Yard and with Dr. DUNCAN were able to enlist some 800 men and women and so organize the study that, to quote Capt. W. G. SCHINDLER, officer-in-charge of the Laboratory, "by the middle of 1942 the problem of creating a nearly perfect defense against the magnetic mine had been solved."....Testing equipment of wholly new types and of unimagined sensitivity had to be created, shipped to stations all over the world, and the flood of resulting observations analyzed and systematized. An extrapolating machine for predicting the magnetic field at all distances from a ship's hull from a relatively few measurements was designed and constructed in 16 weeks; with it two men can complete the study of the largest ship in a single day, whereas a single mathematician with standard computing machines would need a month. Rugged equipment capable of measuring magnetic fields one millionth the strength of the earth's field was devised, then its speed increased so that the field around a de-gaussed ship could be recorded in a few minutes, then increased even further so that accurate magnetic surveys can be made from low flying aircraft.....To provide better for such potent research is naturally first on the construction plans for a $5,000,000 laboratory at Whiteoak, Md., some 12 miles north of the Navy Yard.

Research in the U.S. Navy

New laboratory for magnetic study

Almost ready for occupancy is the first of four non-magnetic buildings, isolated in the center of a 1000-acre plot, even separated each from each some 100 yd., for the very taking of a magnetic measurement creates a magnetic field and this must not disturb other work. Naturally iron and nickel are excluded from these buildings in favor of copper and wood, but did you know that even the bricks, sand and concrete aggregate had to be checked and rejected if it was too "magnetic"? Captain BENNETT said that the principal equipment in each of these outlying buildings is a new device for creating a magnetic

field of any intensity, direction, or variation within a 6-ft. sphere; it consists principally of three opposing pairs of huge induction coils placed on 90° axes.....Permanent staff for the new ordnance laboratory — only one of several now intensely active for the Navy — is already a matter of concern. Such a staff will require the services of some of the top-notch scientific men of the country. This work is of highest importance to our national security and will give opportunity to these men to continue their research and also contribute their knowledge toward developing superior weapons for America. No argument is needed on this point — the Germans, for example, caught us napping with the magnetic mine. We can build more warships than any other nation, but what is more important than numbers is that they should be faster, more seaworthy, better armed and armored, have more accurate fire control and better audio, magnetic and electronic eyes and ears than anything else afloat. Such things are achieved only by constant research and intense development. Without them our defenders will be uselessly sacrificed. With them — and *knowing* their arms are superior — our sailors will be invincible.

Perfect ammunition

TO THOSE who find it hard to believe that accurate production can be controlled by the relatively new methods of statistical analysis, and especially those die-hards who hold to 100% inspection rather than inspection of relatively small samples taken from production, a report from Brig. Gen. JAMES KIRK will be worth pondering. He is chief of the small arms branch of the ordnance department, and he quotes representative figures from one group of soldiers that fired 414,715 rounds of caliber 0.50 machine gun ammunition in a 25-day campaign. (Quality of small arms ammunition, produced literally by the billion, is under statistical control.) In this period only six stoppages occurred, chargeable to gun or ammunition failures! Service tests on ammunition, therefore, prove it to be "failureless" — at least to the extent of 99,999 out of 100,000.

Research for small industry

INTERESTED to learn, from *Metal Progress'* scout who attended the silver anniversary of Standard Oil's development laboratories, that much consideration was given to the needs of small rather than large businesses. No less a person that FRANK B. JEWETT, head of Bell Telephone Laboratories, pointed out that a research organization does not need to be large to be efficient. The large companies in the chemi petroleum, automotive and electrical industry hire most of the technical coming out of universities but, the opinion of EARL P. STEVENS president of Arthur D. Little, I these companies are large pri cipally because they hired technical men wh they were small and kept on hiring them. T substantiates JEWETT's thought that "mon spent through well-organized research and dev opment departments is the least risky and pote tially the most profitable of all the expenditur in which industry ventures capital". Oth speakers said that even though a business cou not have its own research department it cou join with others (as in the paper and gas indu tries) to finance investigations of mutual impo tance, and could have at least one influential sta member who understands the scientific basis the operation, and can appraise and interpr new ideas and developments. Such a man woul guide the firm to proper decisions bearing on it health and very life. Over and over it wa emphasized that research would be barren, com mercially, if its results were not understandingl interpreted to the operating and productio management.

Where are our metallurgists coming from?

ONE MIGHT INTERPRET this weight o expert opinion as meaning that the youn technical man or scientist, soon to graduate eithe from combat duty or university, would have bes chance of usefulness and financial reward i small industry rather than large. Specifically, i metallurgy the beginner would fare better in a iron foundry than in a big production mill o fabricating plant. Let him not be discouraged too easily, for the future belongs to him. A Standard Oil's celebration WESTBROOK STEELE director of the Institute o Paper Chemistry, warned against the tendency o thinking of the future in terms of materials and machinery for, he said, in the final analysis industrial competition is for *manpower*. "My industry must see that it gets at least its share of outstanding young men. If we succeed in this, we shall succeed in all else.".....It is doubtless true that a great number of top executives in small businesses recognize the need of recruiting promising men and know of many opportunities for industrial research; funds would be forthcoming for investigative work were only technical and scientific manpower available. If these small businesses start competing for such personnel it

will doubtless have a good effect on the ruling salary rates, but it cannot do anything toward curing the wartime shortage of good graduates. The supply of young metallurgists is bound to be short for several years. University training in engineering and scientific professions has been all but stopped by the draft into the armed services — and no branch harder hit than metallurgy. The number of metallurgical graduates had been slowly increasing for years up to 1940, but then dropped to near zero in 1944. Even with the best luck in the world the "normal" output, extrapolated from the pre-war curve, will not be reached before 1950, and the graduates permanently lost by non-attendance during the war decade will be a large fraction of the entire number actively engaged in the profession today. Likewise a sizable group *must* remain in educational work, or the whole system will collapse.

NOT SURPRISED, in the light of the above considerations, to find one of the principal objectives of American Brake Shoe Co.'s Research and Experimental Department to be the training of men, at the graduate level, for production and executive positions in the half-hundred far-flung plants of this corporation. While the unusually fine facilities under EARNSHAW COOK's direction at Mahwah, N. J., are recently built, the company is no Johnny-come-lately to the idea that the thriving business is the business that knows how to make a better brake shoe than anyone else, and makes it. As long ago as 1889, the late F. W. SARGENT built a small machine to test the action of brake shoes against chilled iron car wheels, and developed the gray iron block, properly graphitized throughout except on the chilled ends, steel backed and reinforced internally by layers of expanded steel. Even today a separate building, named in his honor, houses equipment far beyond SARGENT's dreams for full-sized tests, still intent on the problem of better braking of high speed traffic — rail, bus or aircraft..... Since much of the Brake Shoe Co.'s production is gray iron castings, a corresponding amount of work in the fine experimental foundry supervised by RAYMOND SCHAEFER is studying this ancient and neglected metal, yet one having enormous possibilities when its melting, alloying, molding and heat treatment are perfected. For this reason there is intent study of sand and other molding materials, of parts cast in centrifugal equipment, of hardening transformations of irons and steels, both plain and alloyed. In fact, the main experimental foundry itself was constructed at the request of the Air Forces to investigate the possibility that air frame parts could be cast with sufficiently high quality to substitute for forgings. Through American Manganese Steel Division (another in the Brake Shoe group) the development laboratory is interested in high alloys, and naturally was drawn into the "investment" or "lost wax" molding process for casting turbine blades....On any such development the research organization is equipped to study the problem from a theoretical or "test tube" viewpoint, then put it into full-sized production (the foundry can make and treat castings weighing up to a ton), work out complete and precise operating instructions and then send men into the chosen plant to get production going and watch things until the regular operators are willing to assume responsibility. An achievement of exactly this sort was honored by the ⚙ at the last annual convention in awarding the HENRY MARION HOWE medal to Messrs. FLINN, COOK and FELLOWS for a paper entitled "A Quantitative Study of Austenite Transformation". The data were acquired while the metallurgical department was learning how to cast and heat treat armor plate, early in the war. The experimental development of such a process — entirely new to the American Brake Shoe Co.'s organization — kept pace with the conversion of an existing plant into

Behold the lowly brake shoe

Advanced study of castings

19-Ton "Hellcats" (M-18 Tank Destroyers) Mounting 76-Mm. Gun in Final Inspection. Speed, firepower, maneuverability on all sorts of terrain are outstanding characteristics. (Photo by Buick of General Motors)

an alloy steel foundry. When the plant was ready the process was ready, as well as a crew of experts ready to see that it got going with the minimum of growing pains.

Something wrong here

ARMY ORDNANCE BULLETIN tells of Pfc. LLOYD L. PATHEAL's bag of one Jap sniper, shot out of a New Guinea palm tree. The dead Jap had a gold Buddha charm around his neck, three lucky rings on each hand, an amulet with good-luck signs strapped around his wrist, 22 good-luck tickets in his helmet band, an anti-malaria and snake-bite charm taped to his left leg, and 14 lucky inscriptions written on bits of silk and stuffed in his pockets which promised to make him immune to American bullets. (He must have forgotten his rabbit's foot!)

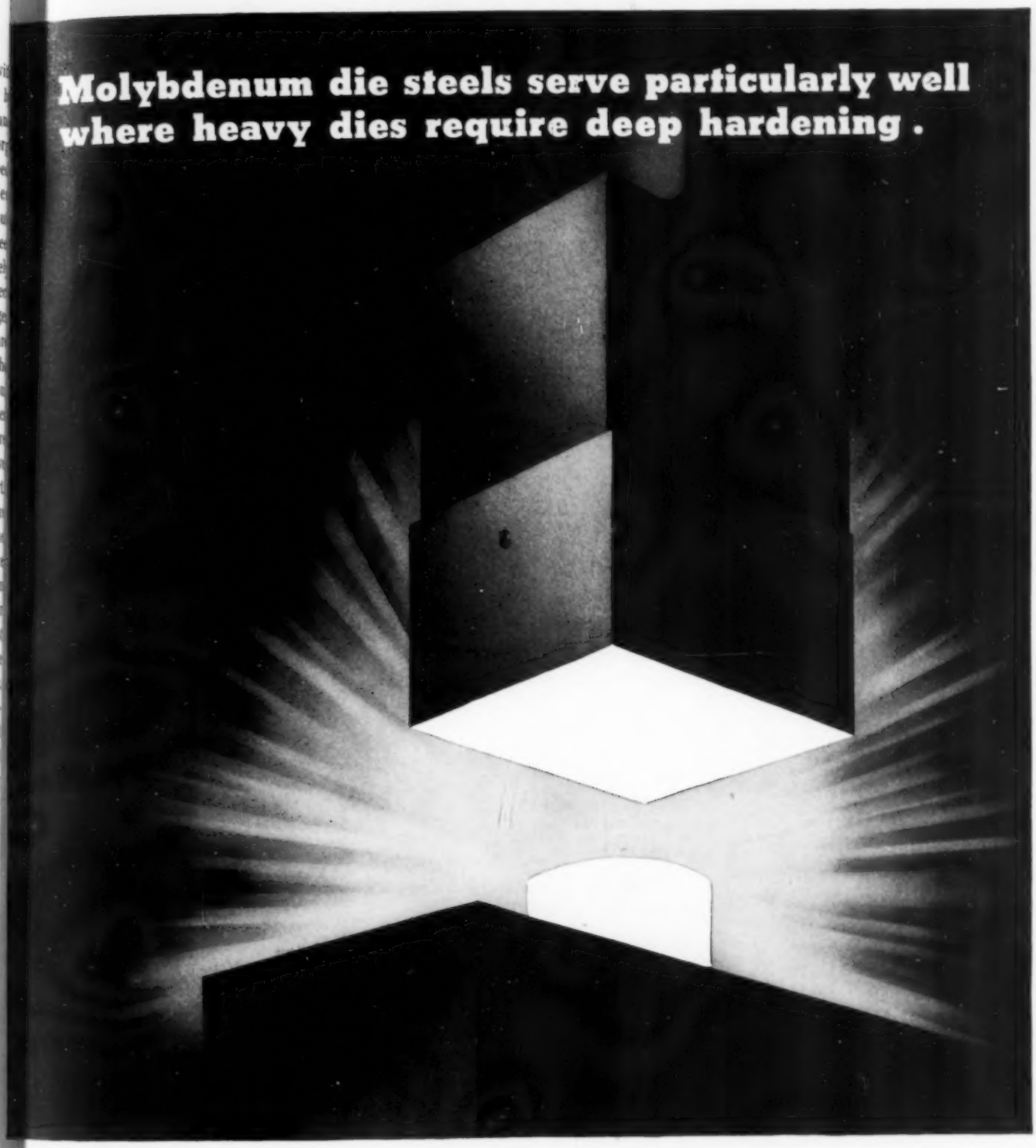
Making nickel and its alloys

REVISITING International Nickel Co.'s Huntington mill in West Virginia after 15 years (checked by digging up some old notes about an inspection trip with WILLIAM MUDGE, metallurgist there at the time), found that the greatest interest still lies in the many similarities yet many differences in melting and pit practices of nickel when compared with steel. Canadian nickel ore is a mixture of iron, copper and nickel sulphides which is concentrated up there to a copper-nickel sulphide low in iron to be used at Huntington for Monel production. Iron can be tolerated in small percentages in some of the high nickel alloys, but sulphur is poison to all of them, so it is reduced to the last trace. Huntington, in fact, was chosen as the site of the works for being near an ample supply of low sulphur oil and natural gas. Melting was originally done in small "openhearth furnaces"; later two 20-ton Pittsburgh 'Lectromelts were installed and much of the metal is duplexed. Pure magnesia bottoms prevent any iron pick-up, a thin carbide slag keeps the sulphur down to a few thousandths per cent. Here again — as in steel metallurgy — a little manganese improves the workability of the metal.....Ingot practice is carefully adjusted for the best balance of several mutually incompatible considerations. The metal must be really dead melted; casting temperature is adjusted for desirable small crystallization; unusually high solidification shrinkage is counteracted by playing a single-phase arc on top the half-frozen ingot, thus producing a veritable hot top to feed the central pipe. (Before this practice was instituted the top discard would be 25%; now it is 5% or less.) Molds are cleaned and washed with extreme care. This reduces surface defects by half, but many are apparently unavoidable (and "healing" is impossible during subsequent forging or rolling) so the ingot is completely scalped a half-inch deep, in huge milling machines. Deeper defects, if any, are then chipped out. Blooms are again inspected and chipped. Sheet bars are also chipped, sometimes completely ground, since it is better to start rolling a perfect surface than to worry about the vastly larger area of the resulting sheet. Nearly all ingots are *forged* to blooms, and the hammermen give the hot metal no mercy, even on the first reduction, experience showing that if an ingot is at all tender they might as well find it out right away before doing a lot of work on it gingerly and then have it turn up anyway in scrap, for the most part. .....My 15-year old notes speak of a continuous roller hearth furnace for process annealing, the sheets taken through on carriers. This furnace is still doing good service; it is heated by open flame, the proportions of natural gas and air being adjusted to minimize oxide with the best combination of CO, H_2O and temperature. The numerous other more recent furnaces for wire, strip, tube and the like, represent almost a historical exhibit of the developing art of bright annealing, and warrant the promised technical article in *Metal Progress*. A long

Bright annealing

furnace caught my eye. The floor of the muffle is of graphite blocks set on edge, and was proposed as a material that would not scratch the strip as it was dragged through. Atmosphere is purified hydrogen, really dried by activated alumina. Surprisingly enough the commercial furnace performed better than its laboratory prototype, and the improvement was traced to a slow reaction between the graphite hearth and hydrogen atmosphere.....Let me also quote HERMAN BROWN, the general manager — words spoken 15 years ago but just as true now: "We have a jobbing mill here, and we make money with our machines, but only when they are *operating*. They run on bearings and are held together with bolts. If the bearings are ample and positively lubricated, and the bolts are oversize and kept tight, you'll have very little trouble. All our mills are equipped with oil circulating systems interlocked with main drives so that if the oil system fails the mill must shut down. This oil is filtered and used over and over again; in 1928 we added less than 100 gal. to the system for make up, and the average cost was about 30¢ per day per mill. In that year also we had 19 min. of delays chargeable to equipment."

Molybdenum die steels serve particularly well where heavy dies require deep hardening.



CLIMAX FURNISHES AUTHORITATIVE ENGINEERING DATA ON MOLYBDENUM APPLICATIONS.

ARMY E NAVY

MOLYBDIC OXIDE, BRIQUETTED OR CANNED • FERROMOLYBDENUM • "CALCIUM MOLYBDATE"

Climax Molybdenum Company

500 Fifth Avenue · New York City

MOLY

PERSONALS

DAYTON A. GURNEY, recently retired as chief ordnance engineer of the Artillery Division of the Ordnance Department, ASF, has been presented the Exceptional Civilian Service Award of the War Department for his contribution to the development of modern artillery over a period of 39 years.

ELBERT A. HOFFMAN, formerly with American Steel & Wire Co., and JOHN M. BIRDSONG, formerly with General Electric Co., have been added to the metallurgical engineering staff of the La Salle Steel Co., Chicago.

PAUL P. BAUERNSCHMID has left the employ of the Waterbury Tool Division of Vickers, Inc., Waterbury, Conn., and has resumed his position with Chandler-Evans Corp., South Meriden, Conn., as production engineer.

EDWARD S. CHRISTIANSEN resigned as vice-president, dire and sales manager of the A Smelting Co., Chicago, to form Edw. S. Christiansen Co. for purchase and sale of magnes and aluminum scrap and finis materials. A. J. PETERSON has b appointed district sales manager Apex.

Promoted by Carpenter S Co., Reading, Pa.: PAUL B. GRE WALD to general superintend of mill operations; GEORGE LUERSSEN to assistant chief m allurgist.

ZAY JEFFRIES, past president technical director of the Lamp D partment of General Electric C Nela Park, Cleveland, has be named a vice-president of Gene Electric Co. and will assume cha of a new chemical department be established probably next ye

S. M. STOLER, formerly vi president of Tate-Jones & Co., h been appointed sales manager the R-S Products Corp., Philad phia, in charge of industrial fu nace sales.

C. J. MCDONALL, former metallurgist and heat treat forem with the Aro Equipment Cor Bryan, Ohio, is now heat treat fo man with the International Detr Corp., Foster Division, Elkhart, In

H. G. MADDOX, formerly wi American Aircraft Parts Co., San Monica, Calif., is now employed b Standard Oil Co. of California, Segundo, Calif., in the equipme inspection division.

LT. ENRIQUE CAVADA, who r ceived the degree of Master of Sc ence in Metallurgy at M.I.T. October, is at present studying th organization of the Philadelph Navy Yard and will return to h native Chile in February.

ANTHONY DEGESERO, former with American Locomotive Co Schenectady, N. Y., is now wit Barium Steel Corp., Canton, Ohi as process engineer.

JOHN M. SPECK, formerl chief tool designer, Rock Islan Arsenal, Rock Island, Ill., is no employed as machine design eng neer by Cherry-Burrell Corp., Ceda Rapids, Iowa.

Superior Hardening @ 1c per Lb!!

Sentry Model Y
High Speed Steel Hardening Furnace

The Sentry Diamond Block Method of Atmospheric Control

for H. S. Steel Hardening when used with

Sentry Furnaces

is economical.

Based on actual Customer Records, summarization of Total Operating Cost for Furnace and all Accessories exclusive of labor indicates a hardening cost for High Speed Steel of 1 cent per pound.

That is **ECONOMY!!!!**

And with economy goes

QUALITY,

Sentry Quality, your assurance of consistently hard tools, free from Scale or Decarburization.

Suitable for High Carbon High Chrome Steels as well as All Types of High Speed Steels interchangeably.

Write for Bulletin 1020-6A

Send Sample Tools for Demonstration.

Sentry "Always on Duty"

The Sentry Company
FOXBORO, MASS., U.S.A.

WORKABLE!

Electric Welded Steel Tube by REVERE

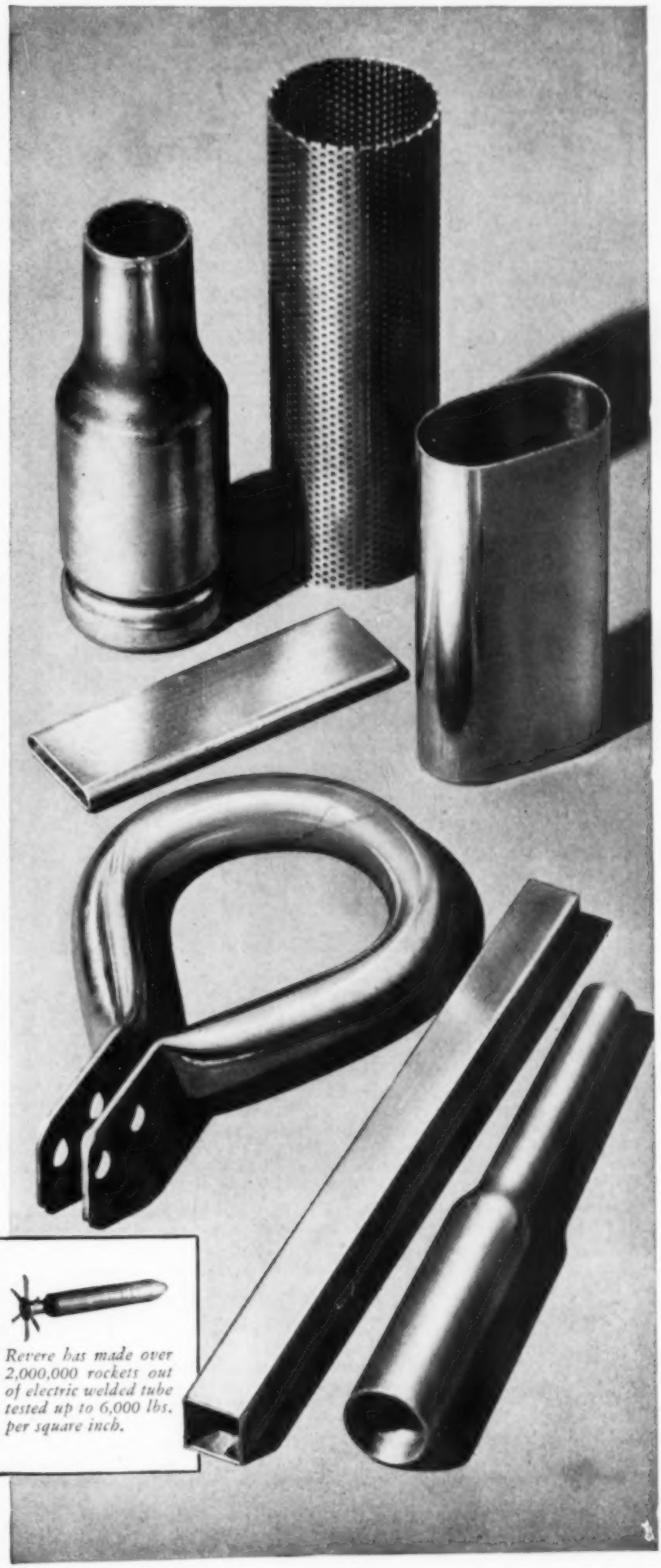
These shapes are just a few of the thousands that have been made of Revere Electric Welded Steel Tube. It is so workable that a great number of parts and products can be made of it. Here are some of the operations customarily performed on these tubes:

Expand	*Plate*
Flange	*Flatten*
Bend	*Taper*
Bead	*Swage*
Machine	*Grind*

Weld

Revere Electric Welded Steel Tube is not just tube. It is available in various exactly-controlled hardnesses, and not only round but in almost any desired shape. It can be supplied in various tempers, annealed or normalized, as required. Dimensional tolerances are held to strict standards. We can process the tube that it is impossible to ascertain the location of the weld. There is literally a Revere Welded Steel Tube for every steel tube use. Sizes up to 4½ inches O.D., wall thickness up to #7 B.W.G., .180 inch.

We not only supply steel tube in straight lengths, but also fabricate it into parts that will fit into your assembly with little or no additional processing. One customer reports saving $9 per unit when he switched to Revere Electric Welded Steel Tube. For further information write the Revere Executive Offices.



Revere has made over 2,000,000 rockets out of electric welded tube tested up to 6,000 lbs. per square inch.

REVERE

COPPER AND BRASS INCORPORATED

Founded by Paul Revere in 1801

Executive Offices: 230 Park Ave., New York 17, N. Y.

PERSONALS

ZOLLY CARLTON VAN SCHWARTZ, formerly engineering coordinator, Firestone Aircraft Co., and mechanical research and development engineer, Firestone Ordnance, Akron, Ohio, is now chief of machinery development in the technical division of the Peck Stow and Wilcox Co., Southington, Conn.

THEODORE H. SANDERSON, formerly assistant superintendent of quality control of the armor plate division, Carnegie-Illinois Steel Corp., Gary Works, has been appointed division superintendent of the armor plate division.

HERBERT W. GRAHAM, director of research and metallurgy, Jones and Laughlin Steel Corp., has been appointed to head the steel mission which is a part of a Chinese "War Production Board" established by Donald Nelson.

ED S. HUDSON, formerly intendent of heat treating w Navy Department at the Na Station in Alameda, Calif., associated with the Western and Tool Works, Oakland, C forging engineer and metall consultant.

FRANK HODSON, formerl allurgist to the Board of Ec Warfare, Washington, and m gical representative on the United States Technical Miss Brazil, has now taken a posi chief technical advisor to the tuto de Fomento Industrial, Colombia.

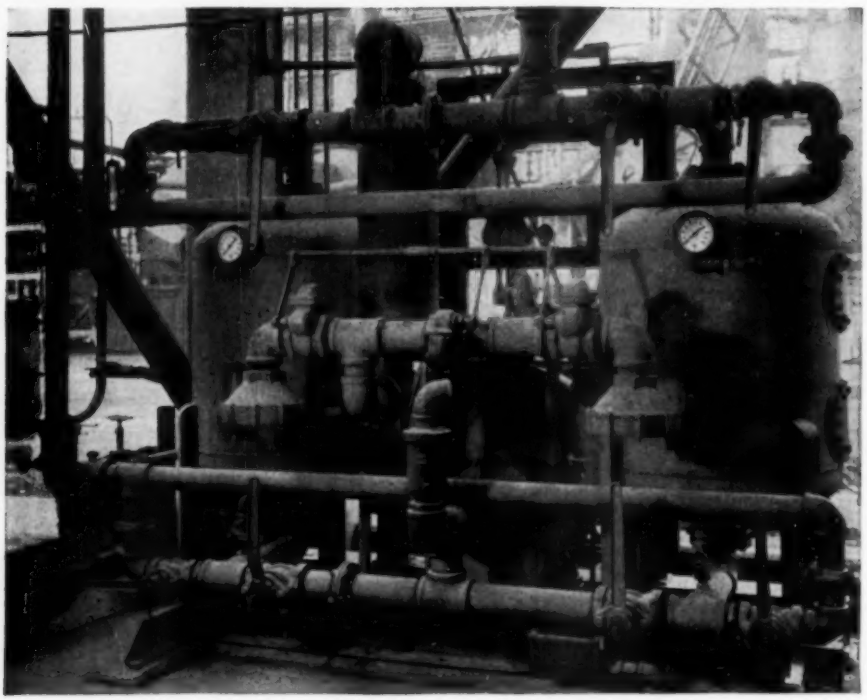
J. RALPH FRITZE, for chief of the Consumer and tural Products Branch, Con tion Division, War Produ Board, has been called to the Department, Washington, D. head the Manufacturing Pro Section in the Conservation sion.

CARL G. DE LAVAL, formerly man for the Electro Metallu Sales Corp. in the tri-state are been appointed vice-preside charge of sales for Pittsburgh Corp., Pittsburgh.

HOWARD LINN EDSALL, a ber of the *Metal Progress* Edi Advisory Committee, formerl vertising manager of the Ajax Co. and affiliates, has bee pointed advertising and promotion manager, Tube Equipment Division, Radio of America. WALT W. Wi previously associated with Automatic Temperature Contr Philadelphia, has been appo advertising manager of the Electric Co., Inc., Philadelphi

KENT R. VAN HORN, for research metallurgist, Alum Co. of America, Cleveland, is assistant manager of the Clev Research Division for Alcoa.

JAMES B. AUSTIN, ass director of United States Steel Research Laboratory, has bee lected to deliver the Edw deMille Campbell Memorial L of the American Society for M in 1946. MAXWELL GENSAM professor of metallurgical eng ing, Carnegie Institute of nology, is the 1945 Campbel turer.



Specify **KEMP ADSORPTIVE DRYERS**

X instruments = 16 men
X instruments + KIA = 2 men

That's what happened at a prominent refinery. When the Kemp Instrument Air Dryer pictured above was installed, maintenance troubles were materially reduced. Two men can now handle the number of instruments that formerly required sixteen because of frequent freeze-ups and clogged orifices. In the face of today's labor shortages that is important news!

Of more importance to refinery officials, however, **is the fact that DRY** instrument air insured functional instrumentation and gave them accurate control of processing.

For accurate, trouble-free instrumentation, specify KIA Dryers. In fact, it would pay you to consider drying all your compressed plant air—our engineers will gladly submit recommendations for your study.

Ask For Bulletin 25-C.

OTHER KEMP PRODUCTS

Nitrogen Generators • Inert Gas Producers
Atmos-Gas Producers • Immersion Heaters
Flame Arrestors for vapor lines, flares, etc.
The Industrial Carburetor for premixing gases
Submerged Combustion Burners
A complete line of Industrial Burners, and Fire Checks.

ARMY E NAVY

Address The C. M. Kemp Mfg. Co. 405 E. Oliver St., Baltimore-2, Maryland.

KEMP of BALTIMORE

Q. What X-ray film for Gamma exposures when time is relatively unimportant?

A. Kodak's Type "A"

KODAK'S Type "A" Industrial X-ray Film, with lead foil screens, is the choice where the materials to be examined can be exposed overnight or when thin-walled castings or welded assemblies are being inspected. Type "A" has fine grain and high contrast and as a result gives superior definition where long exposures are permissible. This increased radiographic sensitivity heightens the visibility of small defects and frequently more than compensates for the longer exposure time required.

When short exposure times are important or when heavy steel parts are to be examined, Type "K," with lead foil screens, offers the highest available speed for gamma-ray exposure.

★ ★ ★

Through 18 years of research and development in the field of industrial x-ray, Kodak has developed a comprehensive line of special films, solutions and accessories for industrial radiography. There are films to meet every industrial requirement. We shall be glad to recommend the type of film best suited to your needs. Manufacturers of radiographic equipment can suggest the equipment for the most efficient inspection of your product.

In Addition To Types "A" and "K" Kodak Makes—

Kodak Industrial X-ray Film, Type "M": Extremely fine grain. "Made to order" for critical inspection of light alloys and for million-volt radiography.

Kodak Industrial X-ray Film, Type "F": Primarily for radiography with calcium tungstate screens where shortest possible exposures are desirable.

EASTMAN KODAK COMPANY, X-ray Division, Rochester 4, N. Y.

Kodak

The Film tells the story

SCIENCE OF SPOT WELDING*

By Wendell F. Hess

MUCH of Professor Hess' paper described the researches at Rensselaer Polytechnic Institute. They were adequately summarized by Martin Seyt in *Metal Progress* for February 1944, in a notable article on "Weldability of Steel". It will be recalled that cooling curves were experimentally determined at various points alongside welded joints, and conditions varied so that a set of tables were worked out whereby the voltage, current and travel of the welding arc can be adjusted to avoid production of unduly hard (quenched) metal alongside the fusion zone.

The summary already published had to do with arc welding of straight seams. The following extracts from the recent A.I.S.I. paper extend a scientific treatment to other types of welding:

Electric Resistance Spot Welding—In this process the cooling rates are commonly so very high that the possibility of transformation of austenite to pearlite at elevated temperature is almost nonexistent. This is particularly true in the lighter gages. For example, in 0.040-in. plain carbon steel with a carbon content of 0.10%, it is possible to obtain a fully martensitic weld structure if the weld is made in 0.1 sec. If a welding time of 0.2 sec. is used, the structure will contain appreciable amounts of elevated temperature transformation products.

Metallurgical literature refers to the possibility of producing a martensitic structure in 0.1% carbon steel by a liquid air quench of thin sections. This indicates the very drastic cooling rates associated with the spot welding process. In almost all cases the actual amount of alloy content has very little effect on the hardness of the resulting structure, since this is to a great degree determined by the carbon content. Due to the very high rates of cooling associated with spot welding, any steel having a carbon content greater than 0.15% will be a difficult steel to spot weld in the lighter gages, unless a subsequent heat treatment is possible by adjusting the welding machine so it maintains heat on the spot. It has been shown in the Rensselaer laboratory to be entirely feasible to temper spot welds automatically with the welding machine, and descriptions of this process have been published.

The best physical properties of spot welds in hardenable steel in all gages up to and including 0.125 in. may be developed by tempering. It has not been found necessary to grain refine the cast structure in these gages of material, probably due to the fact that the structure is already so small due to the weld size and rate of cooling.

For gages of material heavier than ⅛ in. it has been found desirable to grain refine the cast structure before tempering, in order to secure the best physical properties. However, it has also been found that a great improvement in physical properties results from the homogenization—an elevated temperature treatment—even though complete grain refinement is not achieved. These results have not yet been published in detail.

The Specific Problem With Various Welding Processes—Although the specific problem with reference to the scientific approach to welding has been discussed elsewhere, an example will be briefly described for electric resistance spot welding to illustrate the steps involved in the determination of proper welding conditions.

The determination of the proper welding conditions for spot welding NAX high tensile steel, X-4130 steel, and 1020, 1035 and 1045 have been discussed in Welding Research Supplement (American Welding Society) in April 1942, October 1942, and October 1943. These papers deal with the situation arising when it is desired to spot weld material with more than approximately 0.15% carbon. For carbon contents below this amount the problem resolves itself into ... ing an adequate size spot ... (which should be in the neighborhood of three to five times the thickness of the thinnest ... being joined) and also in ... mining the proper pressure ... avoid porosity and internal ... ing. In some cases the matte... surface preparation is of ... importance, particularly for ... rolled and improperly pi... sheets.

It may be of interest to re... the essential features of the pro... tion of tempered spot welds. ... process applies for all spot wel... in gages up to ⅛ in. The requ... equipment includes a co... involving time and current ad... ments for welding followed ... time for quenching to marten... and followed in addition by a ... ther time interval for temper... the spot weld, with accompany... current control during this in... val. Thus, an alternating cur... machine may be equipped with ... phase controls and three tim... adjustments for the purposes ... lined above.

The first step in establish... proper welding conditions exp... mentally in a given joint is to ... regard the tempering operation ... to make welds where diameters ... three to five times the thickness ... the sheet. The *time* required ... making such welds should be ... short as possible; the shorter ... time in which the weld is m... and the current interrupted, ... more rapidly will the weld ... to the proper martensite-form... temperature. The limitation ... shorter and shorter welding t... with higher and higher po... results from the tendency tow... metal expulsion before the pro... size of weld is obtained.

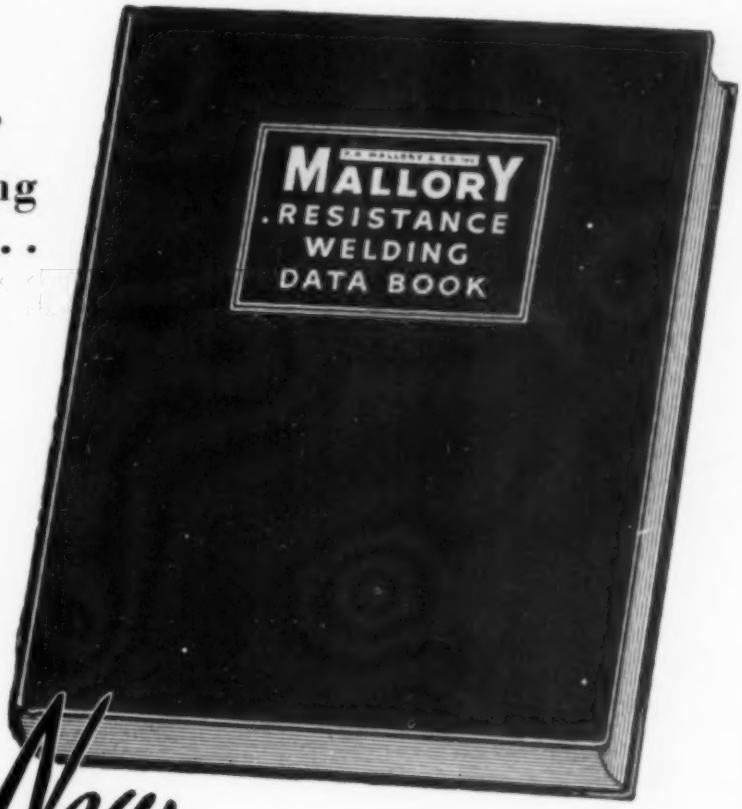
After such satisfactory weld... conditions have been establish... allow a sufficiently long cool... time to insure cooling to mart... site-forming temperatures. A ti... considerably longer than necess... is usually desirable during ... establishment of welding co... tions.

After this quenching time ... been allowed a current is pas... for a length of time either equa... the welding time for thin ga... below 0.040 in., or twice the we... ing time for gages from 0.040 in. ... to approximately ⅛ in. The c... rent control for this temperi... operation is then varied until p...

(Continued on page 116)

*Extracts from paper entitled "Recent Progress in the Scientific Application of Welding to Steel" read before the American Iron & Steel Institute, May 25, 1944.

A "Must" for Welding Engineers . .



The New

MALLORY
RESISTANCE WELDING DATA BOOK

WRITTEN by experienced welding engineers and metallurgists, this new edition of the practical Mallory manual covers every phase of resistance welding . . . provides factual answers for hundreds of questions.

Included in the Third Edition Mallory Resistance Welding Data Book is material on

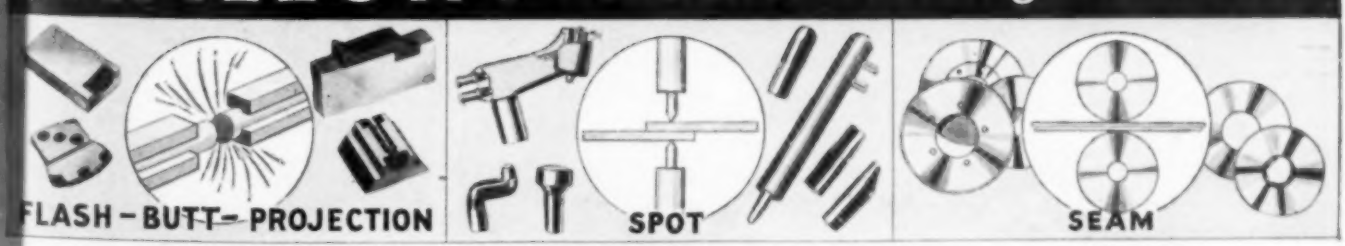
Welding Principles	Controls and Timing Devices	Cooling Methods
Heat Generation	Electrodes	Applications
Resistance Welders	Timing	Special Processes
Resistance Factors	Pressure	Electrode Alloys
Current Requirements		Definitions

Materials to be Welded: Ferrous and Non-Ferrous, Plated and Coated
Do's and Don'ts of Resistance Welding

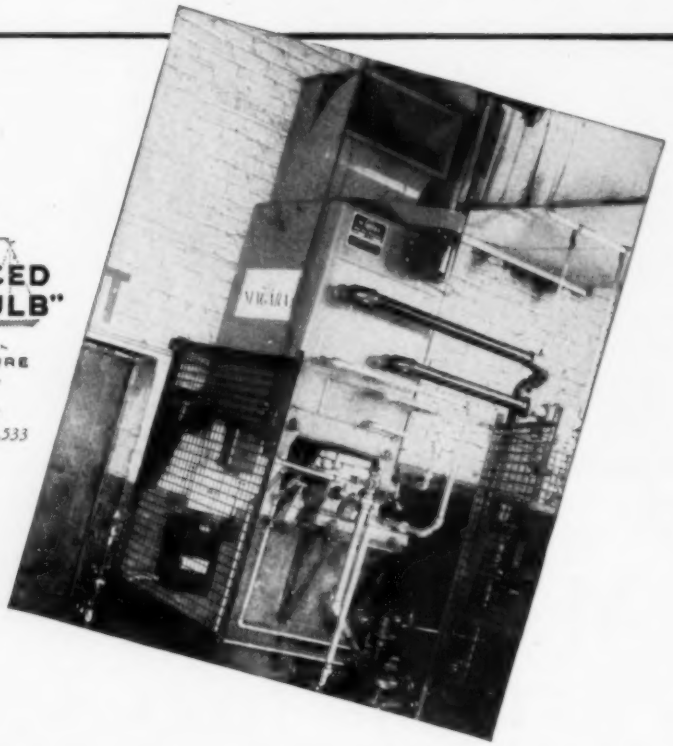
This new Data Book is replete with tables, charts, diagrams and photographs of operations illustrating correct methods of welding. It will be sent gratis to resistance welding engineers when requested on company letterhead. Price to students, libraries and schools is $2.50 per copy, postpaid.

P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

P.R. MALLORY & CO. Inc
MALLORY *Standard Resistance Welding Electrodes*



NEW AERO *After Cooler* GIVES DRY COMPRESSED AIR *and* saves cooling water



With "BALANCED WET BULB" TEMPERATURE CONTROL

U. S. Patent Re-issue No. 22,533

● Compressed air experts say that using more thoroughly dried air would save air tool users thousands of dollars in repairs and thousands of hours in lost time. In many industrial processes, drier air will prevent loss of valuable materials or rusting of delicate parts.

The NIAGARA Aero AFTER-COOLER offers a new method—the application of *evaporative* cooling—which makes possible lower air temperature and compressed air that is drier, safer to use for any purpose. It also provides closed circuit jacket water cooling with the Niagara "Balanced Wet Bulb" temperature control, preventing condensation and the washing of lubricating oil into the air lines.

In operation, it saves 95% of cooling water consumption, paying for itself in saving water cost. Write for Bulletin 98.

NIAGARA BLOWER COMPANY

Over 30 Years of Service in Industrial Air Engineering

DEPT. MP-15, 6 E. 45th St. NEW YORK 17, N. Y.

Field Engineering Offices in Principal Cities

INDUSTRIAL COOLING HEATING • DRYING

NIAGARA

HUMIDIFYING • AIR ENGINEERING EQUIPMENT

WELDING

(Continued from page 114)

nounced increases in weld te ness are observable by mean a chisel test applied between sheets in such a manner as to f the weld apart. When appr mately correct tempering cur has been reached, the welds be very much tougher than in as-welded state.

The length of time betwe welding and tempering (quench time) should then be reduced u the beneficial effect of temperin lost. This indicates that the m has not been allowed to cool fo sufficiently long period to p through the martensite-formi range. By setting the time inter for quenching just slightly hig than that required to produce appreciable increase in weld tou ness upon tempering, the minim satisfactory time will have be determined. Further careful che should then be made to determ the best value and dwell of tempering current.

The adjustment of temperi period is the most critical and most important element in welding process. This is due to fact that the best tempering occ just below the critical temperat of the steel. When too high a te pering current is used, the m in the weld zone will again transformed into austenite, a rehardened on cooling, with resu ant loss of mechanical properti When the tempering current h been increased to a value whi produces an unmistakable loss physical properties, the value current should therefore be reduc slightly. Under these conditio the maximum weld toughness w be secured.

An improvement in she strength and a marked improv ment in tensile strength and impa strength will also be obtained tempering. The maximum propo tional improvement in properti will of course be obtained for t most hardenable types of steel. an example of the possible i provement by tempering spot wel in 0.040-in. S.A.E. X-4130 steel, t shear strength may be improved a factor of 2½, the tensile streng by a factor of 5, and the sh impact strength by a factor of m than 5.